METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER)

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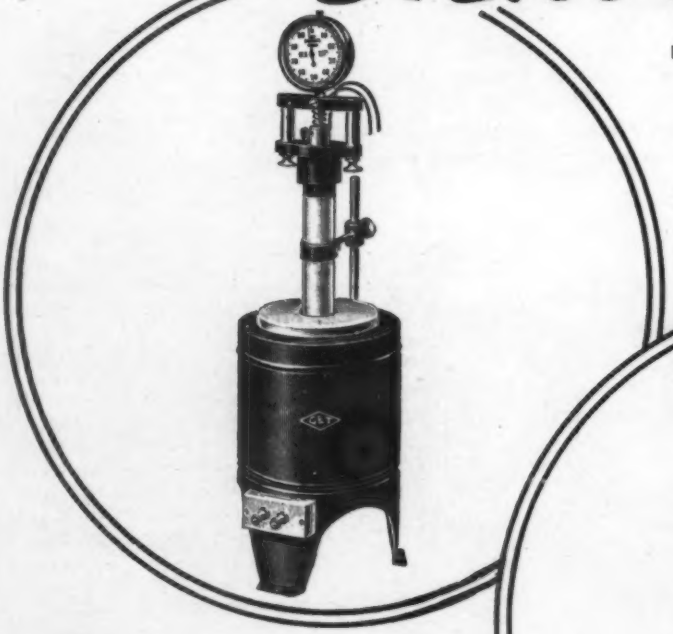

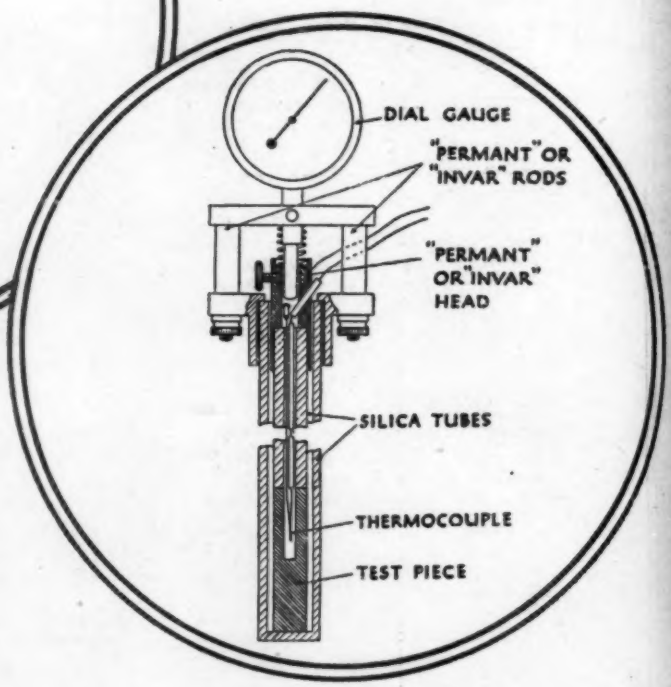

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METALLURGIA

THE BRITISH JOURNAL OF METALS.

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Peace and Security

A PEACEMAKING army composed of representatives from all over the world, has come to Britain to lay the foundation of a world organisation. This General Assembly of the United Nations, as it is known, has, at the time of writing, had its inaugural meeting. On the previous night a State banquet was held at St. James's Palace, and in a speech of welcome to the delegates, King George said that it was in the hands of the Assembly to make or mar the happiness of millions of people ... the rights both of nations and individuals cannot exist and stand secure unless nations and individuals alike are members of an ordered society.

The purpose for which this General Assembly has been formed is so important to mankind and civilisation that it transcends any other topic which could be discussed here. Those of us who are familiar with the efforts made to promote a world organisation after the 1914–1918 war will remember the enthusiasm with which the League of Nations was greeted, but they will also remember how dismally the League failed. All sane people supported the principles of the League in theory but the dilatoriness of nations in carrying out their obligations undoubtedly led to the second great war recently ended. The Belgian Foreign Minister, who was President of the Assembly of the League of Nations just twenty-six years ago, had much to say that will be said in connection with the newly formed United Nations Assembly. "Let us dedicate ourselves to humanity," he said, "working together, let us seek to prepare and, step by step, to achieve the long awaited reign of international morality and human right."

The enthusiasm of mankind for an ordered world society is not less intense than it was a generation ago, but, after past failures, it is not surprising that one sometimes has a feeling of bitterness associated with anxiety. Many familiar with the League of Nations will ask, will history repeat itself? Will selfishness and nationalism, short-sightedness and fear again prevail to destroy the new organisation as they destroyed the old?

While there is considerable similarity between the old and the new organisations, there is one important difference, the United States and the Soviet Union are enthusiastic members of the new organisation, whereas they did not become associated with the League of Nations until 1934. Additional members are: Egypt, the Philippines, Turkey, Mexico, Syria and the Lebanon. This has some significance in determining whether history can repeat itself. But there is another important aspect which must have an important influence on the deliberations of the General Assembly of the United Nations, this is the reaction of the average citizen to war. It is gradually being forced upon him that foreign affairs are his own intimate concern and that they touch his existence to the quick. He has seen that the crimes or mistakes of soldiers or statesmen in a foreign land can lead to the ruin of his own life and happiness, to the death or torture of his sons, of his mother, and of millions of unoffending beings like them; that it can spread want and unemployment all over the world; that it can shatter government, and add to anarchy the horrors of wholesale famine and disease in the countries of Europe and far beyond its confines. Two major wars have been necessary to provide the lesson.

It is true that an effort was made with the setting up of the League of Nations, after the first great war, to effect a fundamental change in the conduct of international affairs. Machinery was set up not only to deal with disputes between nations as they occurred, but with a view to controlling the currents of international politics so far as possible. This was the first and chief reason for the institution of the assembly and council of that organisation and for the powers which they were given. But the success of an organisation of this kind is dependent upon the people of individual nations, the support given, and the competency of delegates to deal with the ultimate problems of international politics, and obligations undertaken to uphold international law must be honoured in spirit as well as in letter, however distasteful they may prove to be.

Nations live, not in isolation, but side by side in ever-growing economic, social, political, and spiritual intercourse; the numerous points of contact thus existing between their citizens create conflicts or communities of interest. These conflicts or communities of interest create in their turn problems roughly similar to those which arise in the internal government of a state; and these require for their regulation some sort of recognised rules of conduct, and some machinery for applying them. It is now more generally realised that every country depends essentially on the prosperity of every other country; that the interests of all countries in quick and easy transit, in sound credit and confidence, in stable government, are not only common to all of them, but are among the vital conditions of their welfare. It is becoming increasingly realised also that if each individual country is to attain the highest level of economic welfare of which it is capable, there must be some organisation through which its economic relations with other countries can be regulated and directed, and this is one of the many duties of the new United Nations Organisation.

Doubtless, in due course, arrangements will be made to set up an international court of justice, which, it is hoped, will rapidly create for itself a position of authority, and a reputation for impartiality, which will make governments ready to take their disputes before it and to abide by its decisions. The Assembly of the United Nations has not met to express pious aspirations but to frame an organisation which will have power to set up such a court with the support of the 51 nations to ensure

that it functions, and to see that it will be ready at all times to meet aggression and put it down. However good the machinery set up to bring about an ordered world society the success achieved must depend upon how it is handled. Mistakes will be made but they can be forgiven if honesty and justice prevail amongst the delegates, irrespective of the interests of their respective countries, so that their decisions are for the common good of mankind. It is probably true to say that the intellectual and spiritual forces count most in the affairs of mankind; if that is so there is need for an informed public opinion which involve instruction in international affairs. An informed public opinion can, and will, transform the conduct of international relations and would be a great help to the work of the new organisation. Let us hope, and help where we can, the organisation to live up to its title.

Secondary Aluminium.

A New Development Organisation

THE collaboration of a group of light metal manufacturers, which found its origin in the days of the war, with the pooling of technical information in the national interest, has resulted in the formation of a development organisation known as "Alar." Through this organisation the co-operative efforts of the technical staff of each of these manufacturers is now being applied to the peace-time requirements of industry. The purpose of this organisation is to ensure that the present high standard of secondary aluminium alloys is maintained and to promote their use by bringing about a wider appreciation of their properties.

This is certainly a move in the right direction and if this organisation can inspire the same confidence in consumers as was eventually maintained during the war, a very valuable service will be assured. While the conservation of metals was essential during the war, the need is very real in times of peace. Common sense as well as economic necessity indicates the more prudent use of ores available, without waste or needless destruction and it must always be remembered that the stock of metal in use is no less a valuable resource than unmined ore.

Real conservation is achieved by promoting the constant use and reuse of that part of production which is not destroyed in service. Thus, the recovery of scrap and wastes, and their use with or instead of metals produced from ores, is sound economics, and entirely in accordance with the general principles of conserving natural resources. The principle is recognised in all the metal producing industries, but, for some unaccountable reason, less attention was given to scrap aluminium in this country before the war than in many other industrialised countries. However, the production and application of secondary aluminium progressed during the war and a high percentage of the total consumption of aluminium comprised secondary aluminium. Under adequate control secondary aluminium was ultimately applied in aircraft production. Control was exercised by the Aeronautical Inspection Department, but with the return to peace-time conditions, much of this control is disappearing and it is the replacement of this control with which this new organisation is primarily concerned.

As readers are aware, the quality and conformity with specifications of the greater part of the aluminium used during the war were guaranteed by an accompanying A.I.D. release note. This inspection system inspired confidence in the use of secondary alloys and the object of the "Alar" organisation is to maintain the advantages enjoyed by the founder by means of control procedure sponsored by the organisation. Under this procedure, which is similar to that employed by A.I.D., alloys are manufactured and inspected in accordance with "Alar" regulations, and an Alar release note is issued to this effect, thus providing the user with an assurance that all the requirements of the appropriate specification have been observed.

It is emphasised that Alar is solely a technical organisation. Its research programme, which includes the development of new alloys, is carried out in close collaboration with other technical and research associations. An important feature of the organisation's policy is the issuing of publications bringing to the attention of present and potential users up to date information on the properties and applications of aluminium alloys. A technical advisory service, with considerable scientific resources, is available without charge to all users of aluminium casting alloys.

The term secondary metal is used to distinguish the product from virgin metal, but this distinction does not imply that secondary metals are of inferior quality, because metals derived from ore or from scrap vary in purity and adaptability to use in making certain products. Indeed, if clean scrap is used and it is carefully graded and remelted under controlled conditions, there is no reason why the secondary metal produced should not compare favourably with many grades of alloys produced with virgin metals. It is noteworthy that two data sheets have already been published by this organisation, one giving a summary of ten secondary aluminium casting alloys, while the second is confined to one alloy—L 33 aluminium silicon casting alloy. The data sheets will be especially valuable to founders; copies may be obtained from Alar Ltd., 6 Old Jewry, London, E.C.2.

Joint Committee on Metallurgical Education

THE importance of scientific and technical education—and especially education in metallurgy—to the Iron and Steel and Non-Ferrous Metals Industries is generally acknowledged. It is, therefore, satisfactory to note the recent formation of a Joint Committee on Metallurgical Education by the Councils of the five leading national Metallurgical Institutes—the Iron and Steel Institute, the Institution of Mining and Metallurgy, the Institute of British Foundrymen, the Institute of Metals and Institution of Metallurgists.

The Committee will advise and co-ordinate the policy of the Councils on all matters concerning education in metallurgy, draw attention to the requirements of industry, advise those responsible for teaching and assist parents and masters in guiding boys in the choice of future careers.

It will be an important part of the duties of this new Committee to supplement the work of the Committee on National Certificates in Metallurgy and the activities of the Councils of the participating Institutions in raising the status and defining the qualifications of metallurgists.

Enquiries will be welcomed and should be addressed to the Secretary at No. 4, Grosvenor Gardens, London, S.W. 1.

The Perrinisation of Basic Bessemer Steel in France

New Slags High in Alumina Deoxidise and Desulphurise

It is now possible to give the interesting developments of the Perrin Process which took place at the beginning of the war, the progress of which was largely interrupted by the German occupation. We are able to do this through the courtesy of M. R. Perrin, who has kindly written a brief historical survey for the benefit of English readers. In effect, he describes the emergence of the basic converter as a producer of high-quality steel, a startling innovation as readers will admit. For those not familiar with his principle, he conceived a rapid metallurgical process which consisted of a violent intermixing of molten steel with suitable molten slags which had intensive purification properties.

THE first practical achievement which took place at the Ugine Steel-works in Haute Savoie, France, of which M. Perrin was General Manager, concerned dephosphorisation. Since then, this phase has been experimented with by the Tata Iron and Steel Co., India, the results of which were communicated by B. Yaneske to the Iron and Steel Institute (Vol. 2, 1940.)

Simultaneously, M. Perrin, also tackled the problem of intensive deoxidation using siliceous slags of sufficient fluidity. The emulsification of these slags in the steel promoted the solution of the iron oxides contained in the metal. He verified his theories that three-quarters of the resident total oxygen could be removed by a violent intermixing, the efficiency of which was startlingly demonstrated by the fact that a complete killing of a rimming composition took place without the further addition of any killing agent.

At that time, in 1934, the Acieries du Nord et de l'Est, Valenciennes, were studying the possibilities of replacing basic open-hearth steel with basic converter steel, with the intention of manufacturing alloy steels straight from the converter, if at all possible. The results at Ugine being of an encouraging nature they signed an agreement with that Company, in order to try and apply the Ugine-Perrin process to the basic converter.

For technical reasons the erection of an electric furnace for the melting of slags at the Valenciennes plant was inopportune. So a cupola was first used, then a rotating furnace, both heavy-oil fired, but neither gave satisfactory results. However, it was established that basic converter steel did respond to the reactions of deoxidation by intermixing with molten slags. Also, they developed a special technique for dephosphorising which removed the usual inconveniences of such an operation in such furnaces.

A semi-commercial production enabled them to supply steels that could be satisfactorily substituted for certain open-hearth steels. However, siliceous slags, used initially, allowed but a partial deoxidation and, of course no desulphurisation. This was a serious limitation but in 1938, M. Perrin, solved this by developing new slags very high in alumina and by their aid obtained both deoxidation and desulphurisation. Their application to the electric furnaces at Ugine and to the basic open-hearth furnaces at Huta-Bankowa, Poland, met with instantaneous success. It was then decided in 1939 to build, at Valenciennes, an installation for the electric melting of slags. In Sept./Oct., 1939, the first heats were run using these molten aluminous slags.

The results were completely satisfactory—the quality produced had a very low sulphur and phosphorus content a high micrographic cleanness and very good physical properties, which complied with the most severe specifications of the French Automobile Manufacturers, Renault for example, who request transverse impact tests.

It then became possible to contemplate the manufacture of high-class alloy steels directly from the converter by addition of the necessary elements followed by an intermixing operation. By the end of the year, 1939, the necessary adaptations were completed and Valenciennes began to manufacture alloy steels on a commercial scale.

The Ministry of Armament, who were informed and interested in these experiments, then gave important orders. By April, 1940, a regular monthly output of 4,000 tons of NiCr and CrMo steels for mechanical parts, case hardening, armour-piercing anti-tank shells, was being obtained at the Valenciennes plant by the new process, thus relieving the electric furnace production of France to that extent.

On May 10, the engineer who had brought these developments to fruition, was to have delivered a lecture in Paris and give a technical review of the work but was detained at the works owing to the invasion of Holland and Belgium. This fortunately avoided any advertisement of the process. In fact, on May 17, the German rush swept France, thus dispersing the staff of the works, but the engineers had taken the precaution of destroying or hiding all the documents relating to the process. Later on, in the summer of that year, the company regained possession of the Valenciennes plant and immediately concealed not only the alloying elements which remained in stock but almost 4,000 tons of alloy steels in varying stages of manufacture. Concealment could be maintained throughout the occupation, not without danger and when liberation came the stock was restored intact to French economy.

When Hermann Röchling was put in charge of the whole ferrous metallurgy of Germany and occupied countries, he came at once to Valenciennes as he knew that something had been achieved, but he failed to get any information. On the other hand, M. Perrin, who kept systematically away, turned a deaf ear to all requests made to him directly or indirectly on behalf of the Germans. Thus, the latter, whose chief object was to convert in some way Bessemer steel into good quality alloy steel, never became acquainted with the new Perrin methods.

As soon as production was again operative at Valenciennes, experimental work was resumed and carried out in great secrecy during the years of occupation. It was found that practically pure iron :—

Carbon	0·02	to 0·03	per cent.
Manganese	0·03	to 0·06	"
Phosphorus	0·015	to 0·020	"
Sulphur	0·008	to 0·010	"
Oxygen	0·002	to 0·005	"

could be produced by Perrinising the basic converter steel with the new aluminous slags. This new product appears to give very promising results and to offer interesting prospects.

The micrographic cleanness of the steel is remarkable. The nitrogen contents range practically between 0·008% to 0·015% as in the so-called German H.P.N. steels. On the other hand, it seems that the very low sulphur and oxygen contents give a metal which should be carefully studied, and in which ageing does not appear to be bound to nitrogen content in the same way as in normal steels. In other words, the removal of a certain number of factors likely to react on the brittleness of iron under certain temperatures or ageing conditions, could modify our present views on the subject. Whatever the explanation may be, it is certain that this is an extremely interesting achievement which may be improved and certainly developed. One should refrain from under-rating it. On the contrary, one should consider the influence it may have in the future on numerous productions, and in particular, on the manufacture of sheets for deep drawing.

The operation technique, which is now far advanced is very simple. Normal basic converter steel at the end of the blow is slagged clean and a new basic slag put on. The steel is not over-oxidised. A ladle containing the aluminous slag is brought to a tapping position under the mouth of the vessel. The special slag previously melted in an electric furnace consists of lime and alumina in suitable proportions. To prevent any phosphoric slag coming over in the tapping operation, lump lime is positioned at the mouth of the vessel forming an effective bridge. The vessel is then tipped quickly enough to give a rather violent intermixing action of the liquids slag and steel in the ladle. Additions of aluminium or ferro-silicon are made to the stream during tapping. The steel when cast into moulds is completely killed.

The ingots roll without difficulty and show no cracks provided they have not been burned in the reheating.

It will be understood that it is easy to obtain many required grades of steel in an equally pure state provided the necessary carburising and alloying elements are added in the ladle. The superheat necessary to melt such additions obviously, will be the limiting factor. But as the superheat is derived from two sources, the molten slag and the steel, the range of possible qualities will be wide.

The apparent simplicity of the present technique is clearly the result of a long period of investigation and tests, but the fact that the officials of the Acieries du Nord et de l'Est did not allow themselves to be discouraged during the period of occupation does great credit to them.

This new process provides for the Continent an easy means of opening out new and far-reaching prospects for basic converter steel. The inferiority complex should vanish as it offers several advantages. First, it is free from heredity as it originates from the ore, whilst open-hearth and electric furnaces depend upon the quality of scrap used. In the second place, the carbon at the end of the blow is generally much lower than in any other process. However, up to now, it has not been possible to make use of these advantages, especially in view of the over-oxidation of the metal arising from the intensive dephosphorising " after-blow."

This obstacle has now been removed and it is interesting to note that the French have thus achieved in the basic Bessemer field much more concrete results than the Germans. The importance given by them to H.P.N. steel, on which they have set such great value, now seems in fact much more a commercial manœuvre aimed at accustoming consumers to basic converter steel, than the result of a technical progress.

Whatever the temporary abundance of scrap on the market may be, England, like other countries, will always have to produce some new metal starting from ores. As she has launched out again in recent years in the basic converter process, which, it should be borne in mind, originated on her soil, it is in her own interest not to overlook improvements in connection with this process, and for this reason we have thought it worth while to give this review.

Industrial Exhibition

THIS year is one of the most momentous which British industry has ever had to face in peacetime. An overwhelming demand for goods both at home and abroad has to be met by industries which in many cases are deficient in manpower and raw materials. Accompanying such demands, there must inevitably be the temptation to produce goods whose sole merit is that they satisfy the moods of the immediate present. Such a manufacturing policy, which ignores the wisdom of making goods to-day that will be their own advertisement to-morrow, would indeed be a fatal error.

Now is the time to break new ground. The world is ready to absorb all the goods which can be produced within the next year or so. Pioneers in design will have an opportunity that may never be repeated. For once they can set the pace, without risk of finding themselves too far ahead of the field. British manufacturers must not only produce goods of first class quality. In doing so they must combine with traditional quality a soundness of design, and a touch of showman's magic, without which complete efficiency in performance and sales cannot be achieved.

In July, the Council of Industrial Design will hold its exhibition, " Britain Can Make It." For the first time in the post-war era, the curtain will be lifted upon representative selection of the products with which industry hopes to capture the goodwill of home and overseas markets. All firms will have an opportunity to compete through the various executive committees which their industries will set up. The Regional Branches of the Ministry of Aircraft Production and Supply, Board of Trade, and Chambers of Commerce, are prepared to advise and encourage firms in preparing their goods for submission to the Council's selection committees.

This is industry's first great chance to demonstrate how British designers and technicians will tackle an industrial test that can only be compared to the military test we faced in 1940. Upon the vigour with which industrialists set about their task will depend our national prosperity for many years to come.

GRAIN BOUNDARIES

By R. C. Bernhoeft, B.Sc.

Metals do not generally have the outward aspect of crystals, because they are composed of a great number of small crystals which have simultaneously grown each from its own nucleus or central starting point until they touch one another. In metallography, the individual crystals are known as grains and the surfaces at which they meet their neighbours are known as grain boundaries, about which many theories have been evolved. In the present paper various theories evolved from 1929 *are reviewed and discussed.*

IN the year, 1929, *F. Hargreaves* and *R. J. Hill*[1] published a paper dealing, amongst other things, with a theory of intercrystalline cohesion and its significance in the phenomenon of work-softening. For simplicity, two lattices are considered, the unit cell of each being a simple cube, having an atom-bearing plane parallel to a cube side in each. Assume that these are both in the same plane and that the boundary of one is a cube face. As one lattice is revolved, we get the following arrangement at 37°-to-the-normal position, as shown on Fig. 1 :—

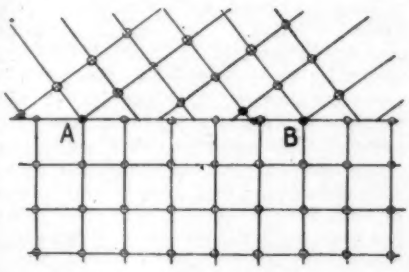

Fig. 1.

This shows that there is a coincidence of normal positions at A and B, that is, every five atom spacings. This pattern will be repeated along the whole length of the boundary between the two lattices concerned. It is conceived that between these points, the atoms will take such positions as will balance the atomic forces resulting. Hence, for each angle of intersection, there exists a definite atomic pattern, representing the lowest potential energy in the circumstances, hereafter called the " transition zone."

In an actual three-dimensional aggregate, with a more complex unit cell, it is conceived that similar conditions to the foregoing simple case will exist. In the case of eutectics and other multiphase alloys, the transition zone will be formed between lattices possessing different constants and, in some cases, between those of different symmetry. In either case, the transition zones will in general be of greater complexity and affect the neighbouring lattices to a greater depth than in the case of pure metals. Another factor influencing the depth is the relative hardness of the two lattices ; in the lead-silver eutectic, for example, the silver lattice would be expected to suffer much less distortion than the lead lattice.

Next is considered the behaviour of *boundaries under stress*. Since the grain boundaries possess a definite structure, they should possess an elastic limit. It is conceived that, after undergoing plastic deformation, the middle region of the boundary has a structure which may be considered amorphous with its attendant properties. A transition zone is pictured on either side of this amorphous layer, not a sharply defined boundary. The thickness of the layer is supposedly proportional to the mechanical distortion inflicted. Quoted is the work of Townsend[2] on " Fatigue Studies." The authors further give as support to their theory, a large volume of favourable opinions and the classical work of Beilby on metal in the amorphous state.

Further support is claimed from the investigation by Gough[3] in which it is shown that the density of polycrystalline aluminium is decreased by working, whilst that of a single crystal is not.

The behaviour of *permanently strained boundaries on annealing* is interesting to follow in the light of these theories. Two actions are possible *in the pure metal.* The transition zones may as it were, eat up the amorphous layer, thus establishing the normal transition zone of the unworked material, or the amorphous layer may recrystallise and result in crystal birth in the boundary. In the first case, remanent stresses in the lattices will in general result in boundary migration in a direction offering greatest release of energy. Crystal growth will therefore take place by a sweeping along of the transition zone, which is evidently a very mobile process.

Now it was postulated that the greater the amount of work applied, the thicker the amorphous layer produced. Consequently it would be expected that crystal birth at the boundaries would require greater application of work than boundary migration. This was in fact, found to be so, by Carpenter and Elam[4] in their experiments on aluminium.

In bi-phase alloys :—here, a sufficient amount of work will result not only in the destruction of the transition zone patterns, but also in an actual mixing of atoms belonging to the two phases. The possible process of recovery is now much more restricted than in the previously discussed uni-phase case of a pure metal.

Almost identical considerations hold whether the alloy consists of two solid solutions of the same constituents or of two different metals. The easiest movement would appear to be the re-establishment of the transition zone pattern.

Phase boundary migration is now out of the question because the lattices are different and crystal birth would demand the adoption of one of the lattices which would upset equilibrium conditions. Relief of stress is therefore much retarded as compared with the uni-phase case. The possibilities left are phase boundary migration where two lattices of the same constituent meet, and recrystallisation within the body of the lattice as in a single crystal.

If during recovery from work, movement of atoms at the boundaries takes place, there should be a suitable

1. J.I.M. 1929 (XLI.).

2. A.S.T.M. 1927. 27. (II.).
3. Cohesion and related Problems. London.

test to detect this. Hargreaves and Hill take this as having been accomplished by reference to the following data on hard-drawn copper :—

	Duration	Annealed	As Received	1 hr. at 100° C.	3 hrs. at 100° C.
Diameter of impression	30 secs.	1·55	1·09	1·09	1·09
	600 secs.	1·56	1·13	1·14	1·12
Factor *s*		0·003	0·007	0·014	0·007
Brinell Hardness		50	104	104	102
B 600		49·2	99·6	95·4	98·1

It is seen that immediately after heating a large increase in the factor s is obtained, where s is obtained from :—

$$d = ct^s$$

d — diameter of impression.
t — time.
c — constant.

s drops again to its former value after 3 years standing. It is assumed that the latter action is the result of the boundary atoms assuming some metastable arrangement and not the result of the establishment of normal transition zones.

On the whole, the paper appears to be of a highly speculative nature. Gough, in the discussion of the paper, says that the authors have drawn conclusions from his work which he himself has not drawn, and refers to their theory as "a very nebulous sort of theory."

In 1937, appeared a paper by *B. Chalmers*[5] on the influence of orientation of two crystals relative to each other on the mechanical effect of their mutual boundary. Specimens consisted of two crystals of tin with a longitudinal boundary prepared so that the lattice orientation of the two crystals with respect to the applied stress direction is the same in all cases, while the angle between the two lattices varies from specimen to specimen. Longitudinal tension was applied. Results show that the critical tension varies regularly with the angle between the two lattices, being a minimum when they are similarly oriented, and a maximum when at right angles to each other. From these results, it is concluded that the boundary itself has no inherent strength and that the results are best explained as the effect of a transitional lattice, evidence being greatly against any amorphous layer theory. A boundary consisting of amorphous material would of course, not give the above results.

In the same year B. Chalmers[6] in a paper on extensometer measurements on tin, again shows that the experimental results obtained are inconsistent with any intercrystalline cement or amorphous layer theory. The experiment deals with creep of tin.

In 1939, *F. Halla*[7] in a book on crystal chemistry gives results showing that the rate of diffusion of one metal into another is inversely proportional to the grain size. This in turn leads to the conclusion that diffusion works much faster along the grain boundaries than along the normal crystal lattice. Some of his experimental figures are : Mo at 1600° C. diffuses into W—powder of 20μ particle size (average) at a rate that is 10× faster than through the single crystal wire. Some idea of the diffusion of Th (D_1 in the single crystal and D_2 along the grain boundary) is given by these figures :—

$$D_1 = 1 \cdot 00 e^{\frac{-120{,}000}{RT}}$$

$$D_2 = 0 \cdot 74 e^{\frac{-80{,}000}{RT}}$$

So, at 2400° K., $D_2 = 100 D_1$. The grain boundaries, therefore, are pictured as disturbed areas where the lattice arrangement is irregular due to the meeting of the two lattices ; that is to say, where the atomic arrangement is some sort of compromise between the two abutting lattices, making it easier for the solute atoms to spread than in an ordered atomic arrangement.

Two years later, in 1941, *C. Benedicks*[8] postulated that two intrinsically different kinds of crystals exist in metals. He calls them random or accidental crystals and polyhedral or capillary crystals. The random grains are such as are formed during a metal's rapid solidification. When random grains are subjected to sufficient thermal agitation to allow the capillary surface which must necessarily exist at grain boundaries to come into effect, we get the polyhedral grain. This surface tension at the grain boundaries explains the tendency of the grains to grow on annealing, which demonstrates a tendency to arrive at a minimum total grain surface. It is then argued that it should, therefore, be possible, in theory at least, to reduce the surface tension at the grain boundaries by finding substances which will dissolve in the metal ; and this effect must be brought about by an enrichment of the grain boundaries with these substances. The enrichment will then tend to stabilise the grain boundaries, and thus prevent grain growth. This result was obtained in practice.

Clarence Zener[9] investigated the elastic properties of a model of polycrystalline metal by assuming that the crystals form a self-locking system in which the crystal boundaries are free to slip and can support no shearing stress. This gave a yield point of about 60% the value obtained on assuming there to be no slip.

In 1942 *T. A. Kontorova*[10] made some theoretical calculations as to the spatial extent and the energy of grain boundaries. In this he assumes that in twin crystals, the twins are separated by some transition zone where we have the atomic orientation gradually merging from that of the mother crystal to that of the twin.

Seitz and Read [11] in a paper dealing with the "theory of elastic properties of solids," discuss the probable nature of grain boundaries. The properties of polycrystals are influenced by two separate factors : (1) the intrinsic properties of the crystals ; (2) by restrictions which neighbouring grains exert upon each other. If it were not for this second influence, *all* properties of polycrystals could be derived from an average of the properties of single crystals for various directions.

Elastic moduli and electrical resistivity can be closely thus approximated ; but such properties as shear strength and internal friction depend to a great deal on the second influence.

The above considerations are fully dealt with by Schmid and Boas[12] .

Since different crystals are pictured as growing from different nuclei, the crystal boundaries will be the regions into which insoluble impurities are pushed, acting as barriers to conductivity. Even with very pure substances, or with highly soluble impurities only being

4. J.I.M. 1920. (XXIV.). 83.
5. Proc. Roy. Soc. (A) 162. 1937.
6. J.I.M. (LXI.) (2). 1937.
7. *Kristallchemie*, 1939, Leipzig. (German.)
8. Kolloid Zeitschrift. (German). 1941. 91. 3.
9. Phys. Review, 1941 (II.). 60.
10. I.M. Abstracts (X.). 1943.
11. J.A.P. (12). 1941.
12. *Kristallplastizitat*. 1936, Berlin. (German.)

present, we can expect some abnormal atomic arrangement in the crystal boundaries, a transitional layer resulting from a compromise between the forces of the atoms in both grains. An important point is brought out here . . . the boundary atoms will not be so tightly bound as the atoms in the interior of the grains, and we can expect them to be more mobile. However, this does not necessarily mean that slip occurs more readily along boundaries, since slip is determined by the ease of formati n and motion of dislocations, rather than by the ease with which individual atoms flow. It is known from other sources that atomic forces in solids extend appreciably only over a few atomic distances, giving boundaries of the order of five interatomic distances wide at the most for fairly pure substances.

As shown in Chalmer's paper, for very pure tin near its melting point, crystal boundaries have a slightly lower melting point than the bulk material. At temperatures not too near the melting point, the bond at the grain boundaries is very strong as evidenced by fractures across the grain. Near the melting point intercrystalline fracture is more common. This is explained as follows: at low temperatures, grain boundaries are weaker than the bulk material, rupture *starts* in them, the crack eventually travelling *through* the grain. At higher temperatures the atomic instability increases and a crack will follow along the boundaries.[13]

In what follows, reference is made to a paper by *Bruce Chalmers*,[14] published in 1940, which seems worth quoting in some detail. Again, we have a specimen of tin consisting of two grains of controlled orientation. The specimens were subjected to tension, and the temperature at which the two grains separated was noted to be below the temperature of melting point of the crystalline material by an amount of the order of 0·14° C. This was found to be independent of the angle of crystal axes of the two crystals when the impurities present were less than 0·02%. The mechanism of formation of crystal boundaries is discussed, and the new evidence is regarded as favouring the conception of a transitional zone lattice in the grain boundary.

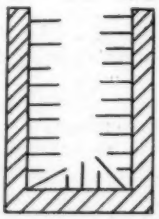

Fig. 2.

Some of the experimental results given are :—

Angle between the two crystals	85°	80°	72°	45°	14°
Temperature, for separation, below the melting point	0·148	0·143	0·139	0·137	0·145

These results are obtained with 99·998% purity tin. With "Chempur" tin (99·986% purity) and 0·05% lead, at 45° angle difference, the temperature difference was 0·24° C.; with "Chempur" tin and 0·2% lead, 0·7° C.: i.e., there must be a considerable impurity increase in order to have an appreciable effect on the temperature difference. (By this "temperature difference" is understood the difference in temperature between the melting point of the actual whole crystal and the temperature at separation, under tension, of the two grains).

It is necessary to form a clear idea of the formation of crystal boundaries before the experimental results can be related to them. This means we shall have to distinguish between two types of crystal boundary, differing in their mode of formation and possibly also in their properties.

The first type of boundary is that which forms between two crystals whilst the latter are both growing. This boundary grows at right angles to the isothermal at the freezing point; that is to say, we have the type of boundary accompanying crystals growing in a direction perpendicular to the cooling surface, such as columnars, Fig. 2.

Chalmers calls these "columnar boundaries." A second type of boundary grows as a result of the following conditions: the solid separating from a melt is purer than the remaining liquid, Fig. 3.

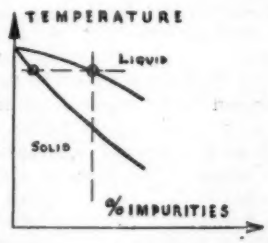

Fig. 3.

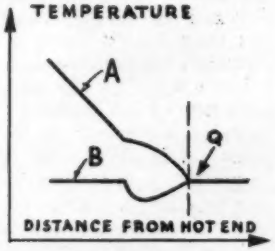

Fig. 4.

This process of non-equilibrium freezing is counteracted by diffusion, and results in a re-distribution of impurities, giving the well-known segregation effect, the impurities concentrating in the liquid near the liquid-solid interface.

Supposing the liquid is cooled from one end, the temperature distribution will be as in Fig. 4.

Due to the re-distribution of impurities, the melting-point will be as in Fig. 4.

A curve showing how far the material is above its own melting point is represented by Fig. 5. "Q" in all these curves represents the solid-liquid interface. Further cooling of the liquid may result either in evening out the melting point curve due to diffusion, or if the cooling is more rapid the lowering of the general temperature may result in the metal at the point "R" reaching its freezing point before the material to the right of it. This will cause formation of nuclei at R, which will grow in all directions. Between "Q" and the existing crystal the boundary will be formed parallel to the isothermal. containing a large amount of impurities. Columnar crystals, growing at right angles to the isothermals, may form between crystals of the type just described, but not between such crystals and the already existing solid. The chief difference between columnar boundaries and the second type, which may be called segregation boundaries, is the mechanism by which the impurities concentrate along the boundaries. The familiar ingot structure is a good example of the two types of boundary growth: The columnar one, due to growth of crystals from nuclei formed at the surface persists until the increased anount of impurities formed in the melt causes fresh nuclei to appear as a result of the process

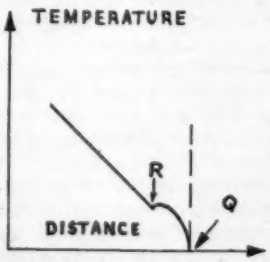

Fig. 5.

13. Seitz: "Physics of Metals," p. 108. McGraw Hill, London.
14. Proc. Roy. Soc. (A) 175. 1940.

described above. These nuclei give rise to an equiaxed structure. It may be noted that in 1937 Professor Andrade and Roscoe pointed out that these may form in the absence of impurities, as a result of cooling conditions. In such cases, curve 4 will be a straight line.

The assumption that the segregation type of boundary grows parallel to the isothermal is probably true only to the general directions of the isothermal, and not in the immediate neighbourhood, since local directions may vary considerably from the general direction due to latent heat disturbances.

The explanation that boundaries fuse at lower temperatures than the bulk crystalline material due to impurities, cannot be accepted, because of the following reasons: As already shown, impurities amounting to less than 0·02% have no appreciable effect on the measured temperature difference. The same conclusion is also reached by the reasoning that there would be no tendency of impurities to collect along the columnar boundaries unless these themselves had a lower melting point. It is also observed that if a crystal boundary moves due to grain growth, fracture takes place at the new position, not at its old site.

This leads to the conclusion that the same material may have different melting points according to whether it is in the state of a crystal or a boundary, which must arise from a different atomic arrangement in the two forms. The two explanations that have been offered are: (1) that the boundary material forms a separable phase in which the atoms are randomly disposed about their normal atomic spacing, and (2) that the atoms are in their geometrically determined positions, on the lattices of the two crystals, as determined by their mutual proximity. Thus we have (1) the amorphous layer; (2) the transitional lattice.

As already stated, the amorphous layer theory can no longer be accepted.

Finally, it is observed that the boundary between a twinned and untwinned crystal does not melt at a measurably lower temperature.

A picture of possible conditions is given by F. B. Foley.[15] Van Wert[16] in his chapter on grain boundaries quotes various theories and does not seem to commit himself in his views to any one of them in particular.

On the whole, that is the summation of the attitude to-day, and the field seems to be a promising one in the way of offering further material for research. Certain anomalies, such as those of conductivity occurring during low temperature ageing in age-hardening material, may possibly then be better understood.

15. "Metal, inside out" A.S.M. 1941. Cleveland, Ohio.
16. "Introduction to Metallurgy," page 113. Van Wert. McGraw Hill. 1936.

Recruitment for Industry

RECRUITMENT by British industry of the best types of operatives, technicians and commercial staffs is imperative if industry is to make its proper contribution to reconstruction and national prosperity in the years ahead. Yet, many difficulties are encountered by responsible firms in obtaining the right type of recruits; however, progressive they may be, the bulk must be provided by the locality in which a particular works is situated. This is often as much a disadvantage to possible recruits as to firms since it imposes limitations in scope for recruits. This problem may be solved in the years ahead, but the prospects of an immediate solution are not good. In some industries, however, the scope is so wide that the majority of recruits can be fitted into those sections in which they are most interested; indeed, in many instances, a probationary period in particular works gives recruits an opportunity to determine their preference at the end of this period and assistance is given in their selection.

For many years now responsible firms have given increasing attention to problem of recruitment for industry and in all industrial areas close co-operation exists between educational centres and works, but, although great care is usually exercised in placing recruits, some undoubtedly become square pegs. Probably this is partly due to the want of knowledge of the firm, with which a recruit is placed, and of the possibilities the firm has to offer. There is a need for enthusiasm on the part of a recruit, which will encourage love of work, joy in creation and satisfaction in accomplishment, but the facilities in the works should provide for advancement to the highest positions those of ability.

This question of recruitment has been taken up very seriously by many firms. Of these, mention may be made of Dorman, Long and Co. Ltd., of Middlesbrough, who have recently published a useful booklet on the subject entitled "Careers in Iron and Steel." Here, one of the largest and oldest firms in the iron and steel industry bring to the notice of young men their desire for recruits to their technical, managerial, commercial and administrative departments and indicate the opportunities open to suitable recruits. Some time ago the announcement was made that this company had created a number of special directorships which were filled by senior officials of the Company; more recently three of them were appointed full members of the Board. The policy behind these appointments is to make the way of progressive promotion clear from apprentice or junior clerk to the status of full director of the Company.

Dorman Long operate collieries, ironstone mines and quarries, blast furnaces and coke ovens, steel furnaces and rolling mills, and they have extensive bridge and constructional department. They have a wide range of products and employ over 40,000 people which include large numbers of staff personnel many of whom occupy executive positions in the engineering, metallurgical, commercial, cost accountancy and other departments. The Company is anxious to facilitate the entry into industry of youths and young men attracted by the opportunity of a technical, scientific or commercial training, *and who are determined to achieve success.*

In a Foreword of the booklet, Viscount Greenwood, Chairman of the Company, says it is our desire to attract to the Company's service, candidates of ability, aptitude and personality, and to assure them of equality of opportunity and sound prospects of advancement. In view of the careful consideration this Company gives to recruitment it can be accepted that it is conscious of its responsibility to train and encourage the progress of all who join this great organisation.

Although the Appointments Department of the Ministry of Labour is doing much to assist the resettlement of men and women in industry, many responsible firms, like that of Dorman Long, are taking more positive steps to find the recruits they need.

The Photometric Determination of Silicon in Aluminium Alloys

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Factors governing the determination of silicon in aluminium alloys by means of the molybdenum blue reaction have been investigated. A method is described which ensures speedy colour development, gives reproducible results, and which has been found satisfactory for the determination of silicon up to 15% in aluminium alloys.

IT is evident from a review of the relevant literature that the photometric determination of silicon in aluminium alloys has been the subject of considerable study, suggesting that difficulties have been experienced in developing a satisfactory procedure.

Procedures based on the formation of the yellow silico-molybdate complex have been developed and described by Hadley[1, 2, 3], Stross[4], and Stumm[5], whilst methods involving the reduction of the yellow to the molybdenum blue complex are the bases of procedures proposed by Vaughan[6], and Haywood and Wood.[7]

The author was concerned with the determination of silicon up to a maximum of 15%, and his attention was given initially to the methods of Hadley and Stross, but it was found that with a tungsten filament lamp and using Ilford Spectrum Violet filters No. 601 in the Spekker Absorptiometer, the drum range was restricted, confirming Stross's findings.

Solution of the Sample

Experiments with published methods employing the molybdenum blue reaction failed to give reproducible results, and in addition difficulty associated with solution of the sample was encountered. Thus, the use of bromine as an oxidant[6, 7], was found to be unsatisfactory owing to the fact that in many instances prolonged boiling was necessitated, and low results were obtained, due probably to the precipitation of silica.

As an alternative oxidant, hydrogen peroxide added after the transference of the caustic soda solution of the alloy to the sulphuric acid, was found to effect complete solution. Prolonged boiling, either to secure complete solution or to remove excess peroxide, was found to be unnecessary, and the risk of precipitation of silica is therefore minimised. The excess peroxide has been found to have no effect on the subsequent procedure; a yellow colour is produced on the addition of the ammonium molybdate, even in the absence of silicon, but this is discharged on addition of the particular organic reducing agent adopted as one result of this work. Experiments in which the excess peroxide was removed by means of potassium permanganate, and the excess of the latter removed by oxalic acid, gave results which showed no significant difference from those obtained without removing excess of peroxide.

Reduction to the Molybdenum Blue Complex

Attempts to prepare a calibration graph using standard silicate solution and employing stannous chloride as a reducing agent failed to give consistent extinction values. Stannous chloride (10 mls.) varying in concentration from 1 g./100 mls. to 1 g./2000 mls. was useless when employed in connection with solutions prepared with hydrogen peroxide as oxidant; incomplete reduction took place with the more dilute solutions, and although reduction was obtained with increased concentration, this was accompanied by hydrolysis of the stannous chloride. Sodium sulphite in the presence of ammonium tartrate[8], also proved ineffective as a reducing agent, suitable pH conditions not being realised.

It was evident that the procedure which the writer has found most satisfactory for securing solution of the alloy, does not permit the use of stannous chloride or sodium sulphite as reducing agents.

Hydrogen Ion Concentration

It was noted in the literature reviewed that 1 — 2 — 4 aminonaphthol sulphonic acid has been used by Olsen, Gee, McLendon and Blue[9] in their work on the determination of silica in leach liquors used in the extraction of alumina from clays, and also by Straub and Grabowski[10] and Bunting[11] for the determination of silica in condensed steam, and preliminary experiments with this reagent gave encouraging results. In order to make use of this reagent for the analysis of aluminium alloys the correct pH conditions for colour development were investigated, using the Cambridge instrument and a glass electrode. A solution of an alloy was prepared as under "Procedure," and increasing amounts of hydrochloric acid (0·5 N) were added to a number of aliquots and the extinction values determined. The pH values of certain of these aliquots were measured at the silico-molybdate (yellow) stage and also at the final (blue) stage, and the figures in Table 1 show that additions of hydrochloric acid (0·5 N) in steps of 1 ml. to 6 mls. give increasing colour intensities, but that over the range of 6 mls. to 20 mls. constant extinction values are obtained.

1 Hadley, W. H., "The Determination of Silicon in Aluminium and its Alloys—I." *Analyst*, 1941, **66**, 486.
2 Hadley, W. H., "The Determination of Silicon in Aluminium and its Alloys—II." *Ibid*, 1942, **67**, 5.
3 Hadley, W. H., "Photometric Determination of Silicon in Aluminium and its Alloys." *Ibid*, 1945, **70**, 43.
4 Stross, W., "Photometric Determination of Silicon in Aluminium Alloys: Observations on Hadley's Method." *Ibid*, 1944, **69**, 44.
5 Stumm, J. J., "Colorimetric Determination of Silicon in Aluminium Alloys." "Symposium on Analytical Colorimetry and Photometry," page 749. Amer. Soc. for Testing Materials, 1944.
6 Vaughan R. J., "Further Advances in the Use of the Spekker Photoelectric Absorptiometer in Metallurgical Analysis." *Inst. of Chemistry Monograph*, 1942.
7 Haywood, F. W., and Wood, A. A. R., "Metallurgical Analysis by means of the Spekker Photoelectric Absorptiometer," Hilger, Ltd., 1944.
8 Boyle, A. J., and Hughey, V. V., "Photometric Estimation of Silicon in Magnesium and Magnesium Alloys." *Ind. Eng. Chem., Anal. Ed.*, 1943, **15**, 618.
9 Olsen, A. L., Gee, E. A., McLendon, V., and Blue, D. D., "Precision and Accuracy of Colorimetric Procedures as Analytical Control Methods (Determination of Silica." *Ibid*, 1944. **16**, 462.
10 Straub, F. G., and Grabowski, H. A., "Photometric Determination of Silica in Condensed Steam in Presence of Phosphates," *Ibid*, 1944, **16**, 574.
11 Bunting, W. E., "Determination of Soluble Silica in Very Low Concentrations," *Ibid.*, 1944, **16**, 612.

TABLE I.

mls. HCl (0·5 N)	Drum Reading	pH at Silicomolybdate Stage	pH at Molybdenum Blue Stage
0	0·27	2·33	4·90
1	0·30	—	—
2	0·37	—	—
3	0·41	1·91	3·15
4	0·42	—	—
5	0·43	—	—
6	0·44	1·68	2·80
7	0·44	—	—
8	0·44	1·56	2·50
10	0·44	1·44	2·35
15	0·44	1·40	2·22
20	0·44	1·26	2·02

Also colour stability is maintained over this latter range of acidity, provided that the standardised volume of reducing reagent is added. (cf. " Quantity of Reducing Agent "). 10 mls. of hydrochloric acid (0·5 N) has been adopted as the standard volume to be added (cf. " Procedure ").

The pH values show that a range of 1·3 to 1·7 is covered at the silicomolybdate stage, and that on reduction a constant extinction value is developed over a pH range of 2·0 to 2·8. Considerable attention has been directed by numerous investigators to the most suitable hydrogen ion concentration for the development of the yellow silicomolybdate colour, and ranges of values have been recorded. These are summarised by Stumm[5] and included in the published account of his work on the colorimetric determination of silicon in aluminium alloys.

Quantity of Reducing Reagent

The effect of the quantity of reducing reagent was examined by adding increasing amounts to similar solutions of an alloy and a reagent blank prepared as under " Procedure " and measuring extinction values at definite time intervals. The results shown in Table II demonstrate that attainment of colour stability within reasonable time is dependent upon the amount of reducing reagent which is added. The addition of 10 mls. produces only a slight increase in colour intensity up to 30 minutes after reduction, whilst the addition of 15 mls. results in stability being attained after 15 minutes and maintained for at least 2 hours.

TABLE II.

Reducing Solution (mls.)	Time after addition of reducing solution (Mins.)	Alloy (Drum Reading)	Reagent Bk. (Drum Reading)
2·5	15	0·46	0·09
	30	0·55	0·14
	60	0·85	0·30
	120	1·52	0·64
5·0	15	0·40	0·05
	30	0·41	0·05
	60	0·44	0·07
	120	0·46	0·09
10·0	15	0·39	0·04
	30	0·40	0·04
	60	0·40	0·04
	120	0·40	0·05
15·0	15	0·39	0·04
	30	0·39	0·04
	60	0·39	0·04
	120	0·39	0·04

This latter volume has been adopted as standard (cf. " Procedure "). Increasing the quantity of reducing reagent beyond this amount offers no advantages although a stable colour is developed, as crystallisation (probably of the amino acid) takes place.

Colour Intensity and Stability

An investigation of the time required to attain stability of colour was also conducted. Solutions of alloys were treated under the conditions described under " Procedure," and the results are given in Table III. A consideration of these shows that the reduction is rapid after the addition of the adopted standard volume of reducing solution, and that colour stability is attained in eight minutes, and is maintained over at least two hours, only slight increases in extinction value being detectable up to three hours. For routine purposes 15 minutes has been decided upon as the time allowed for full colour development after addition of the reducing reagent (cf. " Procedure "). The following procedure has been formulated as a result of the work described.

TABLE III.

Time after Addition of Reducing Solution (Mins)	Alloy No. 1	Alloy No. 2
	Drum Reading	Drum Reading
2	0·43	0·73
8 — 110	0·44	0·74
130	0·45	0·74
150	0·46	0·74
170	0·46	0·74
190	0·46	0·75
240	0·47	0·76
300	0·47	0·76
420	0·47	0·75

Reagents

Sodium Hydroxide, AnalaR (Pellets).
Sulphuric Acid, 25% by volume.
Hydrogen Peroxide, 30 volumes.
Hydrochloric Acid, 0·5 N.
Ammonium Molybdate, AnalaR, 5% Aqueous solution.
Reducing Solution :—

2 g. 1 — 2 — 4 aminonaphthol sulphonic acid, Refined (B.D.H.),
120 g. Sodium Metabisulphite,
24 g. Sodium Sulphite, AnalaR, dissolved in distilled water and diluted to 1,000 mls. (The reagent is not completely soluble, and the solution must be filtered. It should be stored in a dark bottle and kept cool).

Procedure

For alloys containing up to 1·5% silicon weigh 0·5 g., for alloys containing from 1·5% to 15% weigh 0·2 g., of sample into a nickel crucible (50 mls. capacity), and into the same crucible weigh 4 g. of sodium hydroxide. Add 10 mls. of distilled water, cover with the lid, and prevent the reaction from proceeding too vigorously by standing the crucible in cold water. When the reaction has subsided, boil gently for 10 minutes. Cool, and transfer the contents of the crucible to a 250 ml. beaker containing 40 mls. of sulphuric acid (25%). Add approximately 3 mls. of hydrogen peroxide, and stir the solution well. Place on the edge of the hot plate, heat gradually to boiling point and remove immediately from the plate. A clear solution is obtained at this stage. Cool, transfer to a 500 ml. graduated flask and dilute to volume with distilled water.

For the lower range of silicon alloys pipette 20 mls., for the higher range 5 mls., into a 100 ml. graduated flask. Into another 100 ml. graduated flask pipette a second similar portion for the blank. To the colour, add for the lower range 35 mls. of distilled water, or 50 mls. for the higher range,and 10 mls. of hydrochloric

acid (0·5 N). Mix well, add 10 mls. of ammonium molybdate solution, shake, and allow to stand for five minutes. Finally, add 15 mls. of reducing solution and dilute to volume with distilled water. To the blank, add the water and hydrochloric acid as in the procedure for colour development, then add 15 mls. of reducing solution and dilute to volume. Allow to stand for 15 minutes and measure the extinction on the Spekker Absorptiometer using 1 cm. cells and Ilford Spectrum Red filters No. 608. It is essential that a blank determination on the reagents shall be carried out simultaneously, and the correction value applied. Obtain the silicon percentage by reference to the silicon graph.

Note.—It has been found advantageous to impart a high polish to the inner surface of the nickel crucibles, the transference of the initial caustic soda solution of the alloy being thereby facilitated.

Calibration Graph

Two sources of silicon were used to prepare the calibration graph, namely, (*a*) sodium metasilicate and (*b*) a standard aluminium alloy. A solution of sodium metasilicate was prepared containing approximately 1 g. of silicon per 1,000 mls. and transferred to a gutta-percha bottle. Gravimetric determinations of silicon were carried out immediately, the usual precautions of successive evaporations to fumes being observed, to ensure that the silica was precipitated completely, and the final precipitates were treated with sulphuric and hydrofluoric acids. This solution was then diluted so that 1 ml. $\equiv$ 0·0005 g. Si. The calibration was made concurrently with the gravimetric determination, in order to eliminate any errors due to possible decomposition of the metasilicate solution.

Fifteen portions of spectrographic aluminium (Adam Hilger, Ltd.), each of 0·5 g. were weighed into nickel crucibles and dissolved in caustic soda as described under "Procedure," and the diluted metasilicate solution was added from a burette to the respective crucibles in steps of 1 ml. from 1 ml. to 15 mls. equivalent to a range of 0·10% to 1·5% silicon on the lower range, or 1·0% to 15·0% on the higher range. The subsequent treatment was exactly as described under "Procedure" (lower range), and the extinction values obtained were plotted against percentage silicon.

TABLE IV.

Sample	Silicon %	
	Gravimetric (Regelsberger)	Photometric
A (R.R.50)	2·54	2·61, 2·64, 2·51
B (D.T.D.424)	5·72	5·84, 5·79
C (D.T.D.424)	6·09	6·24, 6·32, 6·11
D (D.T.D.424)	6·69	6·88, 6·88, 6·67
E (D.T.D.231)	10·99	10·93, 10·85, 11·02, 11·07
F (D.T.D.231)	11·91	11·74, 11·95
G (D.T.D.231)	11·93	11·90, 11·90, 11·95
British Chemical Standard No. 181	0·39 (certificate figure)	0·42, 0·42
British Chemical Standard No. 182 (List No. 323)	12·74 (certificate figure)	12·83, 12·75, 12·67, 12·78

A second calibration was carried out, the basis of which was a standard aluminium alloy. British Chemical Standard No. 182 containing 12·74% silicon (certificate figure) was employed for this purpose, and commencing with a weight of 0·05 g. successive amounts in steps of 0·025 g. up to a maximum of 0·20 g. (equivalent to a range of 3·19% — 12·74% silicon) were weighed into nickel crucibles, and treated as under "Procedure" (higher range). The calibration graph prepared in this manner was identical with that obtained using the metasilicate solution. Blank determinations on the reagents were carried out simultaneously with both calibrations and the necessary correction applied. One hundred drum divisions on the instrument used were equivalent to 15% silicon in the case of the higher range, hence, 1 drum division corresponds to 0·15% silicon, the relationship being linear. By operating the absorptiometer with the drum aperture fully open (i.e., drum reading = 0) for the coloured solution, the drum reading for the blank gives the extinction value directly.

The method has been used for different types of alloys with satisfactory results, typical examples of which with the corresponding gravimetric determinations are given in Table IV.

Acknowledgment

The author expresses thanks to Mr. A. A. Pollitt, M.Sc., F.R.I.C., for advice and helpful criticism, and to Mrs. K. Hampson for valued assistance with the experimental work. He also wishes to thank Sir Arthur P. M. Fleming, C.B.E., D.Eng., Director of Research and Education, and Mr. B. G. Churcher, M.Sc., M.I.E.E., Manager of Research Department, Metropolitan-Vickers Electrical Company Limited, for permission to publish this paper.

Silicomanganese Alloys in Steelmaking

It is generally understood that with good furnace operation, deoxidation of steel with silicomanganese will produce clean steel faster than can be made by adding silicon or manganese alloys separately. The savings in furnace time and the improvement in quality possible with silicomanganese alloys have led many steelmakers to adopt this deoxidation practice.

The purposes of deoxidation practices are described in a booklet recently published, in which the advantages offered by deoxidation with silicomanganese alloys are emphasised. Melting procedures are described for open-hearth and electric furnaces, and charts are included to help calculate alloy additions. Information is given on the facilities for providing metallurgical assistance. This booklet is published by St. Lawrence Alloys and Metals, Limited, Beauharnois, Quebec, Canada, and copies in English, Spanish, Portuguese, French, and German editions, will be sent to men concerned with steelmaking if they will write on their business letterheads. Interested readers are requested to specify the language most useful to them.

Errata—December, 1945

Page 65.—Col. 1, line 8 from bottom, should read: "This is a logical occurrence."

,, 65.—Col. 2, line 14 from top, read: "2% Mo" for "2% Ni Mo."

,, 66.—Table I, item 120, read "Jumo" for "Juno."

,, 66.—Table I, item 183, read "JU.88.D" for "J.U.88."

,, 67.—Table II, item 183, read "$\frac{1}{8}$ in." for "$\frac{3}{8}$ in."

,, 69.—Col. 1, line 9, read "Molybdenum" for "Chromium."

,, 72.—Col. 2, line 2 (excluding table), read "Brinell" for "Brinnell."

Effect of Preliminary Treatment on High-Speed Steels

By F. F. Dodson

ONE method of increasing the hardness of high speed steel tools, is to immerse in a bath of sodium cyanide operating at 580° C. for a predetermined time. The period of immersion is governed by the characteristics of the tools and the type of work they would be expected to machine. Briefly, this process is a nitriding operation imparting to the surface layers of the steel a nitrogen "case," which is extremely hard and brittle. Excellent results can be obtained in increased life of tools thus treated, providing the operation is carefully controlled; too deep a penetration will cause chipping at the cutting edges, whilst an insufficient depth of "case" would rapidly wear, and in some instances cause chipping through its partial collapse. However, this process is applied to tools that have been hardened, tempered and finish ground to size, whilst the subject to be discussed is a treatment in which the high-speed steel is subjected to a nitriding treatment in NACN before hardening and tempering. The method used by McIntyre* was to immerse the steel in a bath of NACN operating at 790° C. for 1½ hours. The NACN percentage was maintained between 20% and 30%. The test pieces used were 18% W and substitute 6/6, and were of one inch diameter.

The steel after being "nitrided" was hardened and tempered in the usual way.

18% W = 1260° C. oil quench, followed by a double temper of 565° C.

6/6 Sub = 1250° C. oil quench, followed by a double temper of 565° C.

Hardness checks were then taken from the outside to the centre of the pieces, using a Rockwell machine. The results recorded being 68° to 70° and it is claimed that these high figures were constant across the 1 in. sections.

A written discussion on Mr. McIntyre's work was obviously not in agreement with these findings, and suggested that, according to photomicrographs he submitted, the steel had been overheated, thus increasing the hardness. Furthermore, that the increase in the nitrogen content added by the cyanide treatment would not be sufficient to act as a contributory agent to increase the hardenability throughout a one inch section, as claimed by the author.

In order to check these claims the following experiments were conducted, using 18% W and 6/6 substitute high speed steels.

Samples were machined to 6 in. × 1 in. dia. and stamped thus.

18% H = 18% W material hardened and double tempered.

18% N + H = 18% W material nitrided in NACN, hardened and double tempered.

6/6 H = 6/6 substitute hardened and double tempered.

6/6 N + H = 6/6 substitute nitrided in NACN, hardened and double tempered.

The nitrided samples were given 1½ hours at 790° C., cooled in air and washed free from salts before hardening and double tempering. The furnaces used for all operations were of similar types to those used by Mr. McIntyre; comprising a cyanide bath of 30% NACN, and electrically heated preheating and hardening furnaces with controlled atmospheres. After the described treatments had been completed, each sample was fractured, carefully ground and polished, and hardness checks taken from the outside edges to the centre of the sample. Results obtained with a standard Rockwell machine were

(18% N + H) 64·5 to 65·5 Rockwell C scale, throughout the entire 1 in. section.

However, when checked with a Vickers machine, a difference, or gradient, could be detected from the outside edge to the centre of the sample.

Readings were taken 0·005 in. apart, this being calculated with the ocular adjusting device.

Readings of 945 VPN (30 KG Load) were constant for approx. 0·060 in. after which the hardness gradually tapered off to a reading of 867 VPN at the centre of sample.

The hardness readings of the 18% H piece was 890 VPN which tapered off to 850 VPN at the centre.

The 6/6 Sub that had been N and H treated gave 905 VPN for approx. 0·060 in., tapering off to 836 VPN at the centre. The 6/6 sub that had been H treated gave 900 VPN tapering off to 860 VPN at the centre.

From these results it is apparent that the sodium cyanide treatment does slightly enhance the hardenability for a certain depth, but does not increase total hardenability. Furthermore, a hardness of 64·5 to 65·5 Rockwell C is obtainable by ordinary hardening methods. It was then decided to increase the time of immersion in the NACN, using further samples of the same dimensions. These pieces were stamped 2, 3 and 6 respectively, indicating number of hours immersed in the NACN. After hardening and tempering the samples were hardness checked as previous pieces, and the results indicated that there was a slight increase in the detectable "band" of increased hardness.

Since the theory of Mr. McIntyre's work is that the increased hardenability throughout the section is attributed to the increase in the nitrogen content of the steel, it was thought that if similar test pieces were immersed in NACN at 580° C. instead of 790° C., an increase in the nitrogen penetration over the former method would result. This was assumed as the nascent nitrogen formed in NACN is more stable at the lower temperature.

Samples were then prepared and stamped to indicate time of immersion and temperature.

From the results of hardness checking these samples after hardening and tempering, it was obvious that although no phenomenal high hardness was obtained, the detectable "band" of increased hardness was found to be constant for approximately 0·200 in. This depth was fairly equal in all pieces and the hardness figure recorded on the "bands" of all pieces ranged from 890 VPN to 905 VPN. All the experiments were then repeated and although a slight variance was found in the hardness figures of some samples it was obvious that 69 to 70 Rockwell = 1114 VPN could not be obtained even near the surface layers of the steel.

* "Experiments on Sodium Cyaniding of High Speed Steel Prior to Hardening." *American Society of Metals Trans.* **34**, 1945.

DAVID BROWN & SONS (HUDDERSFIELD) LIMITED have notified us of the removal of their London Office, the address now being Haymont House, 3, Panton Street, Haymarket, London, S.W.1, the telephone numbers are now Whitehall 5061/2/3, while the telegraphic address is Dabrogears, 'Phone, London.

A Metallurgical Study of German Aircraft Engine and Airframe Parts

This report constitutes a summary of further data, resulting from the metallurgical examination of German aircraft engine and airframe parts by the Aero-Components Sub-Committee of the Technical Advisory Committee of the Special Alloy Steel Committee formed for that purpose.

The types examined represent a comprehensive range of various types of German aircraft which have fallen into the hands of the R.A.F. from 1942 onwards.

The principal object of these investigations was to obtain data on the types and quality of materials used, methods of manufacture, efficiency of the heat-treatment to which the parts have been submitted, together with any other information which might prove of value, as, for example, details of the finish. Further, the influence of restrictions, due to our blockade, on German procedure and selection of materials was kept in mind. Attention was given chiefly to engine parts but a number of airframe and miscellaneous components were included. Special features concerning design had been noted in certain instances, but these were not the primary object of the investigations. The Sub-Committee responsible for these investigations and for this report comprise; Mr. S. Barraclough, United Steel Companies, Ltd.; Mr. H. Bull, Messrs. Brown-Bayley's Steelworks, Ltd.; Mr. H. H. Burton, the English Steel Corporation, Ltd.; Mr. W. J. Dawson, (Chairman), Hadfields, Ltd.; Dr. R. Genders, M.B.E., S.T.A.M., Ministry of Supply; Mr. H. J. Hipkins, Royal Aircraft Establishment: Mr. N. H. Mason, R.A.E., Farnborough; Mr. D. A. Oliver, Messrs. Wm. Jessop and Sons, Ltd.; Mr. L. Rotherham, Thos. Firth and John Brown, Ltd.; Dr. H. Sutton, Ministry of Aircraft Production; Miss M. K. Walshaw, Secretary, Brown-Firth Research Laboratories.

The work included in this report embraces the results of investigations carried out as a continuation of the data already published. It has been carried out meticulously. Naturally in this Report no comparisons are made with corresponding parts in British and American Aircraft, neither are certain aspects which our investigations have shown to be open to criticism emphasised.*

Section X.—Camshafts

THE first published report referred to two camshafts, one from a Junkers Jumo No. 211A engine (Item No. 7), and the other from a Mercedes-Benz DB.601A engine (Item No. 20). This further note refers to four additional camshafts, all from Jumo engines.

Item No.	Date of Report	Description
120	7/4/42	Camshaft from Junkers Jumo 211F1 engine.
183	2/3/43	Camshaft from a Jumo 211J1 engine.
251	23/12/43	Camshaft from a Jumo 211 engine.
307	17/11/44	Camshaft from a Jumo 213 A1 engine.

Composition

Analyses of the above, together with that of the Junkers Jumo commented upon in the original report, Item 7, are given in Table I.

It will be noted that the earlier Items Nos. 7 and 120 are of the 2% nickel, 2% chromium + ¼% molybdenum type; Item 183 is made from 1% chromium + ¼% molybdenum; the later Items, Nos. 251 and 307, have neither added nickel nor molybdenum, but are 1% chromium steels each containing more than 1% of manganese. This may point to economy in the use of alloy.

* "A Metallurgical Study of German and Italian Aircraft Engine and Airframe Parts," 1943, The Kennedy Press, Limited.

Steelmaking

All the shafts were probably made from basic electric arc furnace steel, and generally of a cleanliness which compares well with that acceptable to British aero engine builders, with the exception that in several of the micro-sections cut from the Items 120 and 307 some odd isolated trails of slag inclusions were observed.

The inherent grain sizes were as follows:—

Item No.	Grade
120	5
183	6
251	6
307	6/7

Forging

All the shafts appear to have been produced by forging (or as forgings).

The grain flow observed in suitably etched longitudinal sections (Item No. 307) through a cam group, and

TABLE I.

Item No.	Type of Engine	C	Si	Mn	S	P	Ni	Cr	Mo	Va
7	Jumo 211A ..	0·13	0·22	0·38	0·008	0·010	1·59	1·75	0·22	—
120	Jumo 211 F1	0·14	0·20	0·54	0·015	0·018	2·03	2·30	0·26	—
183	Jumo 211 J1	0·19	0·24	0·77	0·011	0·020	0·21	1·02	0·18	—
251	Jumo 211 ..	0·17	0·29	1·21	0·020	0·019	0·12	0·92	0·06	—
307	Jumo 213 A1	0·20	0·28	1·18	0·007	0·013	0·10	0·97	0·02	Trace

TABLE II.

Item No.	Type of Engine	Diamond Hardness		Surface hardness on other than cam or bearing.
		Case	Core	
120	Jumo 211F1	793/846	Not observed	406/446
183	Jumo 211J1	821/878	Not observed	367/452
251	Jumo 211	836/883	296/302	264/268
307	Jumo 213A1	753/797	373/396	371/518

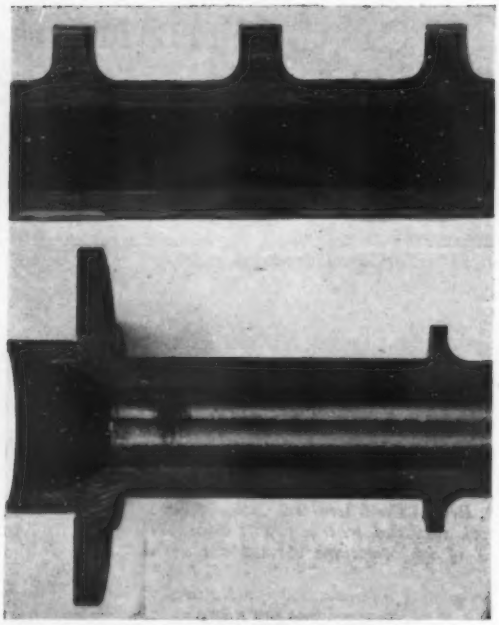

Fig. 1.—(Upper) Section through a cam group.
Fig. 2.—(Lower) Section of large end of shaft.

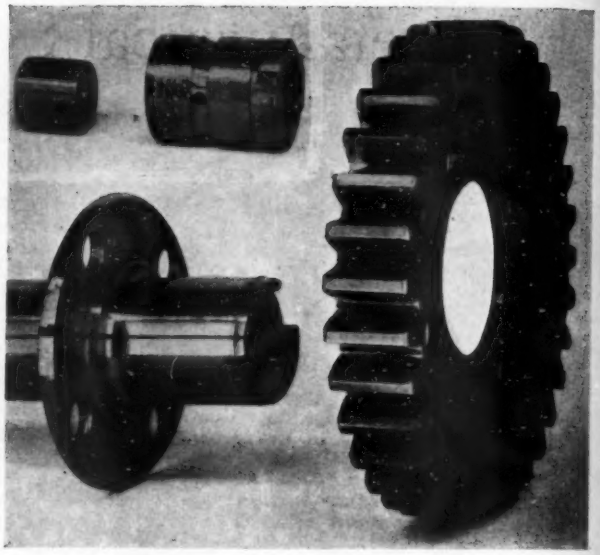

Fig. 4.—Details of pinion and insert and cap, Jumo 211J1.

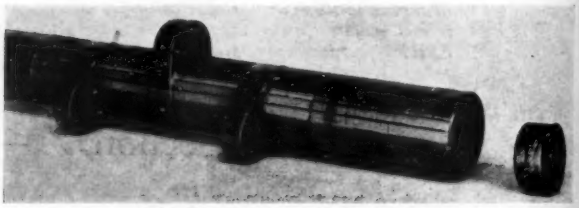

Fig. 5.—Spur wheel end and plug, Jumo 211.

Fig. 3.—(Left) Pinion and cam shaft, Jumo 211F1.

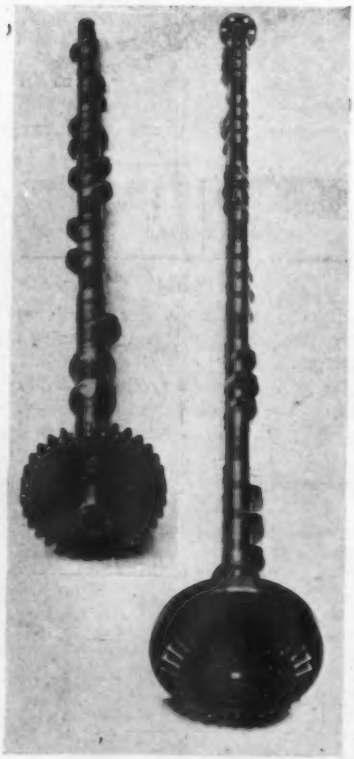

Fig. 6.—(Right) Pinion gear and backing disc, Jumo 213A1

the larger end of the shaft, is illustrated by Figures 1 and 2 respectively.

Hardness Values

Vickers's diamond hardness tests were made at intervals along the full length of the shafts, and maximum and minimum values are given in Table II.

Microscopical Examination

Longitudinal sections were taken from various parts of each of the shafts; a note of the non-metallic inclusions found in the unetched condition in respect of Items Nos. 120 and 307 has been made in the paragraph regarding steelmaking. Etched in picric acid all the shafts were found to be carburised on the wearing parts, the case depth being about 0·04 of an in., except in the case of Item No. 307, which was approximately 0·025 to 0·03 in.

Summary

The composition changes in Table I show economy in the use of alloys. Otherwise the shafts are almost identical in the application of forging as a method of production, and the localisation of carburising to bearing and cam surfaces.

The surface finish by grinding on all surfaces, including the bore, is common to Items 120, 183 and 307, but exceptionally, the surface between the cams and the bearings of Item No. 251, is a mat grey, most probably produced by shot blasting; the bore surface also is shot blasted and not ground.

The illustrations in Fig. 3, Fig. 4 and Fig. 5 are typical of Items 120, 183 and 251, but not necessarily so in precise detail as regards the methods of sealing the ends of the bore. It is to be noted that no pinion was attached to Item No. 251.

The bevel gear and backing disc shown in Fig. 6 (Item No. 307) constitute a new design feature. Further changes from the earlier specimens are the disposition of the cams—each group being practically in line—and the use of a considerably thicker wall.

In addition to the camshaft proper, each sample includes certain auxiliary fittings which are features in the illustrations. Brief details of these parts are given in Table III.

TABLE III.

Item No.	Engine	Part	Composition					Grain Size	Hardness V.P.N.	Method of Manufacture
			C	Mn	Cr	Ni	Mo			
120	Jumo 211F1	Pinion	0·22	0·51	2·00	2·02	0·28	5/6	821/841 (Case)	Upset forging—carburised on teeth only.
183	Jumo 211J1	Pinion	0·21	0·97	0·87	0·05	0·14	3/5	807/826 (Case)	Upset forging—carburised on teeth only.
307	Jumo 213A1	Bevel Gear	0·20	1·23	0·87	0·09	0·11	4/6	812/836 (Case)	Upset forging—carburised on teeth only.
307	Jumo 213A1	Pinion Backing Disc	0·37	1·73	0·15	0·27	0·02	3/5	271/285	Upset forging—hardened and tempered.
120	Jumo 211F1	End Plug (Pinion end)	0·36	0·60	1·03	0·25	0·21	—	285/288	Machined from hardened and tempered bar.
183	Jumo 211J1	Insert (Pinion end)	0·35	0·54	0·83	3·55	0·04	7/8	268/275	Machined from hardened and tempered bar.
183	Jumo 211J1	Cap (Pinion end)	0·32	—	—	—	—	—	187/193	Machined from normalised or hot-rolled bar.
251	Jumo 211	Inserts (Splined plug, spur wheel end)	0·42	0·55	1·01	Trace	0·27	3/5/6	351/356	Machined from hardened and tempered bar.
251	Jumo 211	Inner Plug (Spur wheel end) (est.)	0·30	0·75	0·02	Trace	Trace	2/4/5	167/177	Machined from annealed bar.
120	Jumo 211F1	End cap (Plain end)	Dead soft carbon steel					—	—	Cold pressed to shape.
183	Jumo 211J1	End cap (Plain end)	"	"	"	"		—	—	" " " "
251	Jumo 211	Plug (Plain end)	"	"	"	"		5/6	167/182	" " " "
183	Jumo 211J1	Bolts	0·38	0·65	0·99	0·06	0·18	6	300/302	Machined from hardened and tempered bar.
		Nuts	0·35	0·84	1·13	0·33	0·25	6	277/278	Machined from hardened and tempered bar.
307	Jumo 213A1	Bolts	0·37	1·76	0·06	0·09	Trace	7/8	304/308	Machined from hardened and tempered bar.
		Nuts	0·30	0·92	0·10	0·11	Trace	5/7	237/239	Machined from "as rolled" bar.

Section XI—Cast Components

THIS examination has been carried out on components which can be divided into two types. These are undercarriage parts which were represented in the series already reported, and wing spar connections of which only one example has been previously met.

In the earlier series the components were all of one type of composition but in the present batch, amongst the wing spar connections, several varieties are represented even in those cases where the function is the same.

Surface Appearance

The surfaces had been shot blasted and then painted, except in the case of the mating faces, in which instances they were machined. Visual inspection revealed no lapping or major surface blow holes, the castings generally having a good appearance.

Soundness

The only unsoundness which was revealed was mainly in the form of interdendritic weakness, this occurring in the wing spar plates at the junction of the thin and thick sections (Items 285 and 299).

Segregation

Such segregation as has been found to exist as indicated by sulphur printing showed this to be of a very small order.

Composition

The knee piece (Item 173) consisted of a 1% Cr Mo steel similar in composition to those previously examined, as did also some of the wing spar plates, the other undercarriage component (Item 273) being a 1% Cr V steel. Amongst the wing spar plates, some were found to be made from material differing in composition from the 1% Cr Mo mentioned above. These included the following types of steel:—

¾% Cr Mo V
1% Cr
1½% Mn V
1¼% Mn

The range of carbon content employed was slightly higher than that found in the previous examination, the maximum value being 0·33% in the case of plate A2/1 (Item 285). Silicon content varied to a greater extent than previously, the minimum value tending to be lower. The high degree of purity as regards sulphur content has been maintained, but on the other hand, the phosphorus content is markedly higher, there being relatively few cases in which the values were as low as the general range of that previously found which was, with one exception, 0·005/0·016%. An interesting feature is exhibited in the Cr V steel universal joint housing, inasmuch as the manganese is nigher than the chromium, being of the order of 1%. This tendency has been observed in certain wrought components from the more recently examined aircraft. Nickel and copper were present as accidentally introduced elements, only to a moderate degree. Where molybdenum appeared to be present as a deliberately added constituent, it did not in any instance exceed 0·21% and was generally less than found previously. In most of the components, vanadium was found to an extent which suggested that this was introduced as a constituent of the raw materials, rather than as a deliberate addition.

Steelmaking Process

There was no evidence to suggest that the process adopted differed from that in the case of the previously examined components, where it was concluded that the basic electric arc process had been employed.

Cleanness

The nature and number of inclusions present were such, that from this standpoint, the castings could be regarded as having a fairly high degree of cleanness.

Microscopic Examination

All the components appeared to have been quenched and tempered, since the structure was generally sorbitic in the thinner sections, and showed a slight aggregation of the ferrite and carbide in the thicker sections. All of the wing spar components which were examined showed coring, but this was not present to an undue extent, taking into consideration that these were castings. The evidence indicated that the heat-treatment was satisfactory. Grain size as determined by the McQuaid Ehn method was found to

TABLE I.—GENERAL EXAMINATION.

Item No.	Component	Aircraft	Description of Component	Soundness
173	Undercarriage Strut, Knee piece and Axle	Focke Wulfe 190 A/2	An L shaped tubular casting with a flange on the axle at the end nearest the bend. The knee piece was only machined on the bolt bosses. The axle had a fine machined finish whereas the shank fitting into the lower end of the plunger was less finely machined.	Apparently sound.
273	Undercarriage Leg. Universal Joint Housing	Messerschmitt 210	This was cylindrical in form, 7·3 in. long with two arms through which pass a pin supporting one of the torsion hinges. The arms are at an angle of 64° to the base and are 4·25 in. apart. Contact surfaces ground, remainder sand blasted.	Apparently sound.
285	Wing Spar Joint Plates	Dornier 217E-4	The plates were bolted together in pairs, there being two pairs from the top flange and two from the bottom. Designated for convenience :— Top Flange .. .. A1/1 and A1/2 bolted together. " " .. .. A2/1 and A2/2 " " Bottom Flange .. .. B1/1 and B1/2 " " " " .. .. B2/1 and B2/2 " " The castings were generally shot blasted but in some instances, grinding had been carried out on certain portions.	Sections taken through A2/2 and B1/2 showed on unetched micro sections some interdendritic porosity.
299	Portion of Main Wing Spar Side Plates	Dornier 217K	Four plates bolted together in pairs, the general thickness, except at the bosses, being of the order of 6 mm. The finish was very variable being smooth machined in some areas, a finish suggestive of sand blasting and ground in others. Plates designated A1, A2, A3 and A4 for convenience.	Micro sections were examined from plates A1 and A2 in two positions, viz. : (*a*) across the junction where the two plates meet at right angles. (*b*) Through the thick and thin portions of the lugs. In all cases there was some porosity mostly at the junctions and little elsewhere.

TABLE III. COMPOSITION AND MECHANICAL PROPERTIES.

Item No.	Component	Aircraft	Composition %										Test Piece Location	Test Piece Dimension	Mechanical Tests								Hardness
			C	Si	S	P	Mn	Cr	Ni	Mo	V	Cu			L.P.	P.S.t.s.i. 0·1 %	P.S.t.s.i. 0·2 %	P.S.t.s.i. 0·5 %	Y.P. t.s.i.	M.S. t.s.i.	E. %	R.A. %	Izod ft. lbs.	
173	Undercarriage Strut Knee piece and Axle	Focke Wulfe 190 A/2	0·28	0·47	0·008	0·012	0·57	0·97	0·07	0·19	Nil	—	—	—	—	—	—	—	—	79·0	17·1 $\frac{1\cdot4}{\sqrt{A}}$	39·1	—	351/382 D.P.H.
273	Undercarriage Leg. Universal Joint Housing	Messerschmitt 210	0·25	0·33	—	—	1·03	0·77	0·07	—	0·19	—	—	—	—	—	—	—	—	—	—	—	—	304 D.P.H.
285	Wing Spar Joint Plates	Dornier 217E-4	Plate A1/1 Top Flange																				Thin Section / †Thick Section
			0·28	0·37	—	—	0·65	1·0	<0·1	0·21	<0·1	—	Corner Portion		—	—	—	—	—	—	—	—	321 Br. / 307 Br.
			Plate A1/2 Top Flange																				
			0·25	0·30	—	—	0·61	1·0	<0·1	0·18	<0·1	—		0·25 in. dia.	—	—	—	—	63·5	69·6	13·5	33·0	—	311/321 274
			Plate A2/1 Top Flange*																				
			0·29	0·46	0·009	0·027	0·66	0·96	0·08	0·20	<0·1	0·12			—	—	—	—	—	—	—	—	—	340 340
			Plate A2/2 Top Flange*																				
			0·33	0·27	0·007	0·027	0·56	0·91	0·06	0·13	0·21	0·18	Corner Portion	0·1595 in. dia.	—	—	—	—	57·0	62·0	17·5	46·0	—	293/302 291
			Plate B1/1 Bottom Flange																				
			0·26	0·35	—	—	0·56	0·92	0·12	0·19	<0·1	—			—	—	—	—	—	—	—	—	—	311/321 270
			Plate B1/2 Bottom Flange*																				
			0·30	0·39	0·006	0·019	0·65	0·95	0·08	0·14	<0·1	0·15	Corner Portion	0·152 in. dia.	—	—	—	—	54·5	63·4	20·0	48·0	—	286/293 273
			Plate B2/1 Bottom Flange																				
			0·22	0·31	—	—	0·59	1·0	0·15	<0·1	<0·1	—			—	—	—	—	—	—	—	—	—	298/286 266
			Plate B2/2 Bottom Flange																				
			0·22	—	—	—	0·55	1·0	<0·1	<0·1	<0·1	—			—	—	—	—	—	—	—	—	—	302/311 266
299	Portion of Main Wing Spar	Dornier 217K	Plate A1																		$\frac{1=4}{\sqrt{A}}$		Thin Plate / Thick Lug
			0·28	0·33	0·006	0·021	0·65	1·05	0·04	0·17	Nil	0·11	Junction of sides Lug		—	—	—	—	57·3	—	64·6	12·0	47·5	—	320 269
															—	—	—	—	51·3	—	57·4	16·5	37·0	38	
			Plate A2																				
			0·27	0·33	0·008	0·018	1·54	0·09	Tr.	0·02	0·08	0·11	Junction of sides Lug		—	—	—	—	54·1	—	60·9	18·5	47·5	—	302 269
															—	—	—	—	49·4	—	56·3	20·0	38·0	18	
			Plate A3*																				
			—	0·35	—	—	1·25	0·1	<0·1	<0·1	<0·1	—			—	—	—	—	Plate A3	—	—	—	—	—	302, 293, 286
			Plate A4*																				
			—	0·45	—	—	0·55	1·05	<0·1	<0·1	<0·1	—			—	—	—	—	Plate A4	—	—	—	—	—	302, 311, 286

* Chemical Analysis. All other determinations except C by spectrographic methods.

† Near bolt hole.

TABLE II—MICROSCOPIC EXAMINATION.

Item No.	Component	Aircraft	Micro-examination	Inclusions Examination and Segregation	McQuaid Ehn Grain Size
173	Undercarriage Strut, Knee piece and Axle	Focke Wulfe 190 A/2	Slight evidence of a dendritic structure consisting of mottled dense sorbite interspersed with ferrite. The component had been hardened and tempered.	Clean	4/6 Mainly 5
273	Undercarriage leg. Universal Joint Housing.	Messerschmitt 210	Dendritic structure consisting of ferrite and pearlite having also a marked Widmanstätten pattern.	Clean	1 and 5 to 7 Mainly 1.
285	Wing Spar Joint Plates	Dornier 217E-4	Plates A2/2 and B1/2 show coring with fine sorbitic structure	Cleanness is quite good in A2/2 and B1/2. Others not examined	A2/1 — 7 A2/2 — 7/8 B1/2 — 7
299	Portion of Main Wing Spar	Dornier 217K	Sections taken at (*a*) Junction where two plates meet at right angles. (*b*) Junction of thick and thin portion of lug. All four plates show that in the thin sections the structure was finely sorbitic and at the thick portion at the lug, a ferrite-carbide aggregate with free ferrite.	Cleanness of high order in all cases. Inclusion count on A1 and A2 were 31 and 36 respectively. Majority of the inclusions were cluster-like and angular in form.	A1 — 6 A2 — 6

be fine with the exception of the universal joint housing (Item 273).

Mechanical Tests

Details of these are given in Table III. The knee piece (Item 173) had been heat-treated to a similar tensile strength to the one previously examined, viz. of the order of 75/80 tons per sq. inch, but in the present case the excellent ductility values obtained were striking, having approximately double the elongation and 50% higher reduction of area value of the former. These differences were not explainable either by composition or any other observed inherent quality of the steel. Tests have been taken from certain of the wing spar plates (Item 299) from the thick and thin portions with a view to determining the comparative response to the effect of mass, and it did not appear that within the limits concerned, that there was much difference in the behaviour of these two materials which were 1% Cr Mo and 1½% Mn V steel. The 1½% Mn V gave a much inferior Izod value to the 1% Cr Mo, but since tests were only taken from the thicker section, it could not be stated to what degree, if any, this difference was attributable to mass effects as opposed to any natural tendency of the material. Brinell hardness values were determined on all the wing components in the thin as compared with the thick sections, and showed varying degrees of difference even within the same category of composition. In every case the wing components have been heat-treated to a tensile strength of 55/65 tons per sq. in.

General Remarks

An outstanding feature of the results of the present examination was the excellent mechanical test results on the knee piece, the ductility values of which easily meet the British Standard Specification for wrought materials. Several types of composition have been applied for the same or similar duties as wing plate components, these generally being of a 1% Cr Mo steel or less highly alloyed material. It would not appear that the use of the latter has been detrimental for the particular application involved. It was noticeable that as regards phosphorus content, in many instances this was somewhat higher than found previously. On the other hand, the proportion of sulphur was still maintained at a low level. The quality of the castings was equal to the high standard observed in the previous examination.

Section XII—Miscellaneous Engine Parts

THE following items are dealt with in this section :—(A) Supercharger parts; (B) Injection pump parts; (C) Valve actuating parts; (D) Crankcase, BMW 801 engine; (E) Exhaust driven turbine wheel.

A. Supercharger parts

(Jumo 211 and BMW 801 engines).

Several components of the Supercharger assemblies examined are dealt with fully in the Section on Gears. Details of the composition, etc., of other parts are given in Table I. The main components are shown in Figs. 1-6. Apart from clutch plates (plain carbon steel), clutch segments and gland rings (cast iron), all the parts were made from chromium-molybdenum, chromium-vanadium, or chromium steels. The majority had been made by the basic electric arc process, the exceptions being the rollers from the free wheel bearing (Item 189), inner clutch housing (Item 195),

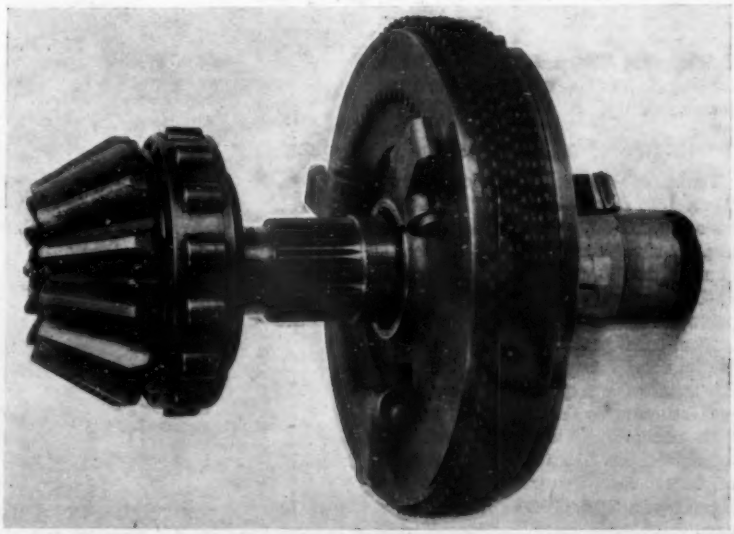

Fig. 1.—Jumo 211J1 supercharger driving shaft assembly.

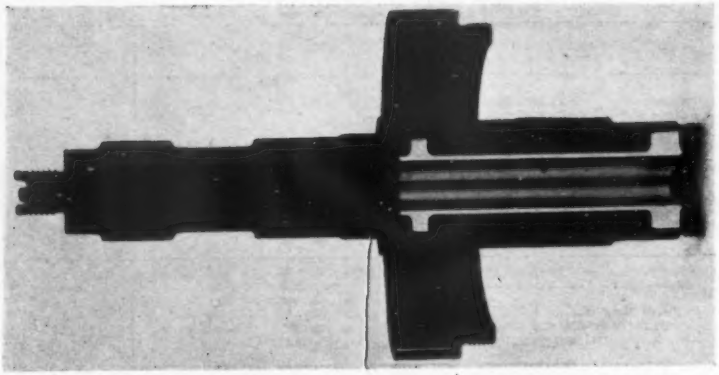

Fig. 2.—Section of Jumo 211J1 supercharger driving shaft.

corresponding to a tensile strength of about 67 tons/sq. inch.

The plunger, barrel, roller and pin had all been made from 1% carbon, 1·3% chromium steels, used in the fully hardened condition, the diamond hardness numbers ranging from 823 to 890. The tappet sleeve had been made from a 1¼% chromium molybdenum steel, hardened and tempered to a diamond hardness number of 477—corresponding to a tensile strength of about 104 tons/sq. inch.

C. Valve actuating parts

1. *Cam wheel, BMW 801A (Item 149).*

This component, previously described under Gears, is shown in Fig. 9.

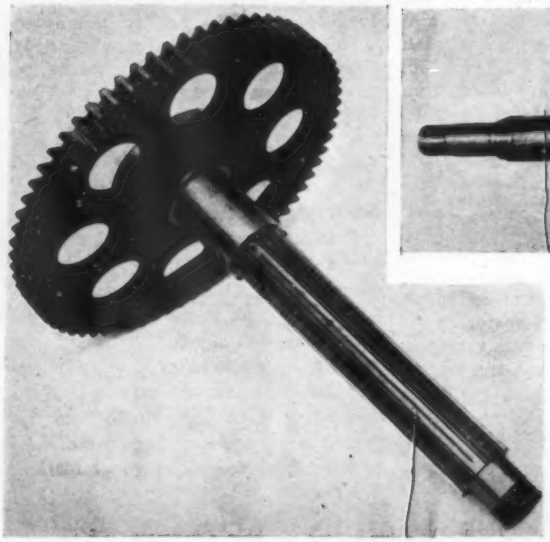

Fig. 4.—BMW 801A main gear box spindle and gear wheel.

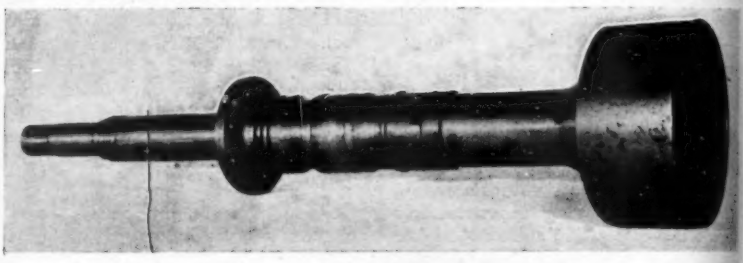

Fig. 3.—Jumo 211J1 impeller shaft.

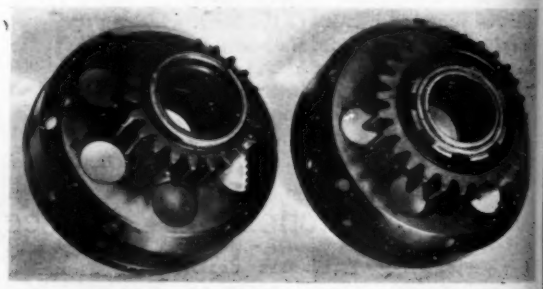

Fig. 5.—BMW 801A clutch outer housings.

clutch plate (Item 151); and large housing (Item 200), which were of open hearth quality.

B. Injection pump parts

Parts of a fuel injection pump (Item 152) from a BMW 801A engine were examined, and are shown in Fig. 7 (cam plate), and Fig. 8 (barrel, plunger, and tappet assembly). Details of the composition, etc., of the various parts are given in Table II.

The cam plate consisted of two forgings held together by bolts and rivets. The cam side of the cam plate had been made from a high carbon, high chromium steel, hardened and lightly tempered to a diamond hardness of 883. For the gear side of the assembly, a 2½% chromium-vanadium steel had been used, hardened and tempered to a Brinell hardness of 305,

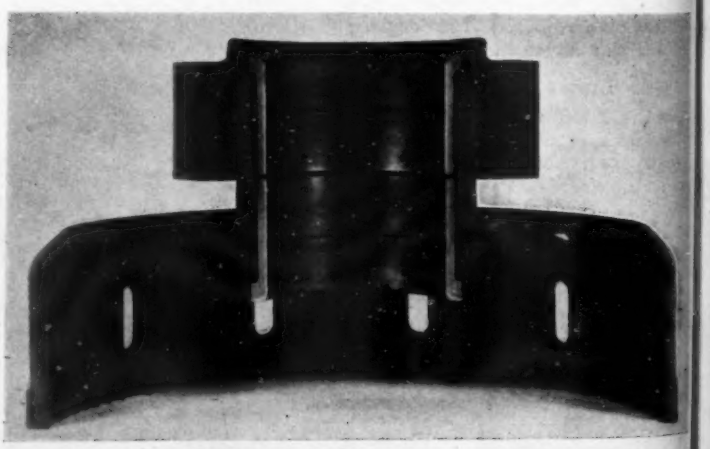

Fig. 6.—Section of BMW 801A high speed clutch housing, showing gear welded to housing.

Fig. 7.—Cam plate, BMW 801A injection pump.

Fig. 10.—BMW 801D exhaust valve rocker arm.

Fig. 8.—Barrel, plunger, and tappet assembly, BMW 801A injection pump.

Fig. 11.—Section of BMW 801D exhaust valve rocker arm.

It had been made as a drop forging from a good quality 1¼% chromium, 1½% nickel steel containing molybdenum and vanadium, and carburised to a depth of 0·04–0·06 inches over practically the whole of the surface. It had been smooth ground all over, and coated with a greenish coloured lacquer. Diamond hardness tests gave values of 752–792 on the carburised surfaces, and 434–496 in the body.

TABLE I. COMPOSITION, ETC., OF SUPERCHARGER PARTS

Item No.	Type of Engine	Component	Composition, %												Grain Size	Diamond Hardness		Remarks
			T.C.	Gr. C.	C.C.	Si	Mn	S	P	Ni	Cr	Mo	V	Cu		Case	Core	
188	Jumo 211J1	Supercharger Drive :—																
		Driving Shaft	0·16	—	—	0·27	0·82	0·008	0·011	Tce	1·09	0·21	Nil	0·03	3–5	824	298/309	Splines case carburised
		Clutch Plates	0·70	—	—	0·38	0·58	0·015	0·023	0·08	0·42	Nil	Nil	0·12	6–7	—	437/460	
		Roller Race	1·09	—	—	0·27	0·35	0·006	0·012	0·11	1·51	0·03	Nil	0·07	—	—	804/823	
		Rollers	1·06	—	—	0·31	0·33	0·013	0·024	Tce	1·49	Nil	Nil	0·03	—	—	829/842	
189		Free Wheel Disc	0·20	—	—	0·18	1·32	0·005	0·013	0·26	1·36	Nil	Nil	0·13	2–5	742/768	466	Case carburised
		Do. Bearing Housing	0·25	—	—	0·29	1·32	0·011	0·014	0·06	1·35	Nil	Nil	0·12	5–6	722/752	450	Case carburised
		Do. Roller	0·98	—	—	0·29	0·31	0·024	0·025	0·03	0·97	Nil	Nil	0·16	—	—	810	
191		Impeller Shaft and Centrifugal Clutch :—																
		Impeller Shaft	0·49	—	—	0·25	0·68	0·006	0·012	0·12	1·06	0·09	0·12	—	7	—	314/320	
		Clutch Housing	0·49	—	—	0·24	0·64	0·010	0·011	0·06	1·09	0·01	0·18	—	—	—	299/327	
		Clutch Segment	3·14	2·33	0·81	1·66	0·77	0·160	0·199	—	—	—	—	—	—	—	196/224	Cast iron
192	Jumo 211F1	Clutch Segment	3·12	2·05	1·07	1·25	0·83	0·116	0·14	0·11	0·09	Nil	Nil	—	—	—	177/199	Cast iron
193	BMW 801A	Main Gear Box Spindle	0·29	—	—	0·42	0·59	0·008	0·010	0·14	2·44	0·21	—	—	6	797/851	324/330	Nitrided
194		High and Low Speed Clutch																
		L.S. Outer Housing Body	0·17	—	—	0·21	0·83	0·014	0·011	0·41	1·11	0·12	Nil	—	6	671	343	Teeth case carburised
		H.S. Outer Housing Body	0·18	—	—	0·37	0·83	0·020	0·013	0·33	1·08	0·23	Nil	—	5	689	398	Teeth case carburised
195		L.S. Inner Housing Body	0·17	—	—	0·17	0·81	0·022	0·025	0·04	0·85	0·37	—	0·08	1–6	810/897	279/318	Splines and teeth carburised
		L.S. Clutch Plate	0·62	—	—	0·31	0·50	0·033	0·047	0·02	0·18	—	—	0·34	—	—	462/487	
196		Clutch Plate	0·64	—	—	0·28	0·44	0·029	0·043	0·06	0·27	Nil	Nil	0·13	6		481/496	
197		Selector Fork	0·26	—	—	0·34	0·4–0·7	0·012	0·011	0·3	1–1½	3·5	Tce	—	—	649	400/425	Surface chill hardened
198		Selector Sleeve :—																
		Body	0·21	—	—	0·21	0·83	0·007	0·012	0·28	1·00	0·20	—	0·07	2–3	819/835	388/410	Case carburised
		Sleeve	0·18	—	—	0·28	0·83	0·007	0·013	0·33	1·03	0·28	—	0·10	6–7	786/804	429/449	Ends case carburised
200		Gland Rings and Housings :																
		Rings	3·54	3·02	0·52	2·87	0·60	0·096	0·59	0·05	0·10	—	0·10	—	—	Brinell	222/253	Ti 0·14 Cast Iron
		Large Housing	0·40	—	—	0·30	0·65	0·042	0·033	0·27	1·09	0·23	Nil	0·11	3–5	—	310/333	
		Small Housing	0·46	—	—	0·28	0·60	0·010	0·012	0·13	1·50	Tce	Nil	0·08	4–6	—	295/302	
201		Slinger Ring—Small	0·32	—	—	0·3	0·5	0·012	0·008	0·1	1·2	0·25	Nil	—	—	Brinell	217	
		Do. —Large	0·30	—	—	0·3	0·5	0·011	0·008	0·1	1·2	0·25	Nil	—	—	Brinell	187	

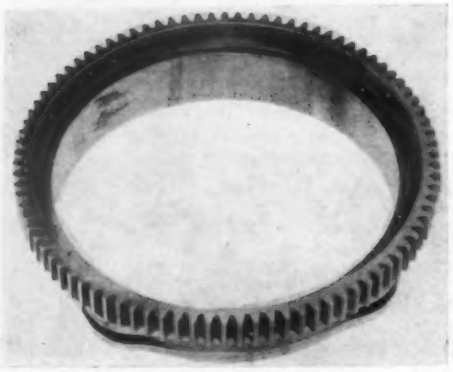

Fig. 9.—BMW 801A valve cam wheel.

2. *Valve rocker arms.*

Two similar rocker arms have been examined, from a BMW 801 D engine (Item 171), and a BMW 801G engine (Item 270). A general view of item 171 is shown in Fig. 10, and an etched section showing the various parts is shown in Fig. 11. The compositions of the component parts of both items are given in Table II.

The main body had been made as a forging in a 1% chromium steel containing 0·2% molybdenum in one case and 0·1% vanadium in the other, hardened and tempered. The push rod cup seating, tappet ball and bearing pads, i.e. parts subject to wear, were in both cases made from a 1% carbon, 1–1½% chromium steel of the type normally used for bearings.

In item 171,1% chromium-vanadium steel was used for the screwed sleeve, and 1% chromium steel for the thimble carrying the tappet ball and bearing pad. The corresponding parts from item 270 had been made from a 1¼–1½% manganese steel. A reduction of the alloy content of the lock nut in item 270 was also noted.

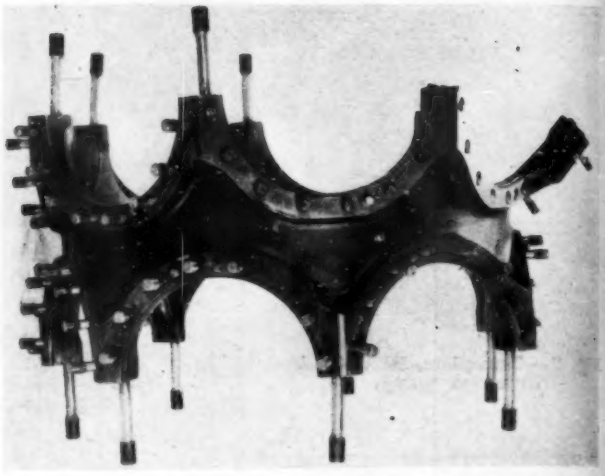

Fig. 12.—BMW 801A centre-section crankcase.

D. Crankcase centre-section, BMW 801A (Item 167)

Two views of the component are shown in Figs. 12 and 13. It consisted of a machined forging into which were screwed connecting and cylinder flange studs, and locating pins. Details of the composition, etc., of these parts are given in Table II.

The main forging had been made from a 0·4% carbon, 1% chromium, ¼% molybdenum steel, hardened and

TABLE II. COMPOSITION, ETC., OF MISCELLANEOUS ENGINE PARTS.

Item No.	Type of Engine	Component	Composition, %													Diamond Hardness		Remarks
			C	Si	Mn	S	P	Ni	Cr	Mo	V	Cu	W	Ti	Grain Size	Case	Core	
152	BMW 801A	Injection Pump Parts:—																
		Cam Plate, Cam Side	2·26	0·42	0·30	0·017	0·019	0·14	13·20	0·09	Tce	0·11	—	—	—	—	883	Drop forging
		Cam Plate, Gear Side	0·31	0·36	0·66	0·007	0·009	0·14	2·46	0·14	0·21	0·14	—	—	—	—	302—309	Do.
		Plunger	1·01	0·21	0·32	—	—	0·06	1·27	Tce	Nil	0·11	—	—	6	—	873	Machined from bar
		Barrel	1·07	0·18	0·26	—	—	0·04	1·34	Tce	Nil	0·11	—	—	6	—	823–873	Do. do.
		Tappet Sleeve	0·23	0·16	0·80	—	—	0·06	1·23	0·20	Nil	0·22	—	—	4–5	—	477	Do. do.
		Roller	0·97	0·29	0·22	—	—	0·16	1·4	<0·1	—	—	—	—	6	—	823–856	Do. do.
		Pin	0·95	0·33	0·24	—	—	0·14	1·3	<0·1	—	—	—	—	—	—	856–890	Do. do.
		Valve Actuating Parts:—																
149	BMW 801A	Cam Wheel	0·25	0·28	0·38	0·009	0·010	1·56	1·84	0·34	0·14	0·12	—	—	—	752–792	434–496	Case carburised
171	BMW 801D	Exhaust Valve Rocker Arm:																
		Body	0·42	0·29	0·60	0·010	0·013	0·41	0·96	0·17	—	—	—	—	5	—	265–295	Forging
		Push Rod Cup Seating	1·02	—	0·33	—	—	—	1·14	Tce	—	—	—	—	—	—	807–812	Machined from bar
		Screwed Sleeve	0·49	0·16	0·67	0·010	0·013	0·06	1·09	Tce	0·16	—	—	—	7	—	318–320	Do. do.
		Lock Nut	0·35	—	0·42	—	—	1·83	2·42	0·28	0·09	—	—	—	7	—	326–330	Do. do.
		Tappet Ball	1·04	—	0·30	—	—	0·03	0·94	Tce	—	—	—	—	—	—	797–817	
		Bearing Pad	—	—	—	—	—	—	1·32	Tce	—	—	—	—	—	—	740	
		Thimble	0·50	—	—	—	—	—	1·06	Tce	—	—	—	—	—	—	331–335	
270	BMW 801G	Valve Rocker Arm:—																
		Body	0·48	0·22	0·67	0·033	0·013	0·10	0·98	0·03	0·11	0·15	—	—	—	—	315–334	
		Push Rod Cup Seating	1·08	0·18	0·33	—	—	0·07	1·47	0·01	—	Nil	—	—	—	—	786	
		Screwed Sleeve	0·35	0·24	1·56	0·014	0·036	0·09	0·05	0·03	—	0·13	—	—	—	—	337–346	
		Lock Nut	0·56	0·15	0·66	0·013	0·031	0·20	0·95	0·04	0·10	0·21	—	—	—	—	329–335	
		Tappet Ball	1·02	0·21	0·31	—	—	0·14	0·96	0·03	—	0·14	—	—	—	—	786	
		Bearing Pad	1·02	0·27	0·32	—	—	0·08	1·35	0·03	—	0·09	—	—	—	—	757	
		Thimble	0·28	0·30	1·31	—	—	0·11	0·13	0·03	—	0·15	—	—	—	—	301–317	
167	BMW 801A	Crankcase, Centre-Section:															(Brinell)	
		Main Forging	0·39	0·27	0·56	0·012	0·011	0·22	1·18	0·24	—	0·10	—	—	2–8	—	235–262	
		Connecting Studs	0·46	0·24	0·66	0·023	0·017	0·03	0·96	Nil	0·17	0·16	—	—	—	—	332–340	Cadmium coated
		Cylinder Studs	0·56	0·26	0·55	0·013	0·009	0·10	1·00	0·02	0·10	0·10	—	—	—	—	340–351	Zinc coated
		Locating Pins	0·50	0·18	0·82	—	—	0·01	1·18	Nil	0·07	0·06	—	—	—	—	302	
288	Jumo 207	Exhaust Driven Turbine Wheel:—															(Brinell)	
		Disc	0·09	0·62	0·35	0·012	0·014	8·60	18·02	Nil	—	0·18	0·90	0·46	—	—	241–248	
		Blades	0·13	0·53	0·52	0·010	0·014	8·70	18·18	Nil	—	0·18	0·90	0·4°	—	—	241–248	
		Pins	0·15	0·67	—	0·011	0·013	8·13	18·37	0·17	—	—	0·77	0·66	—	—	332–340	

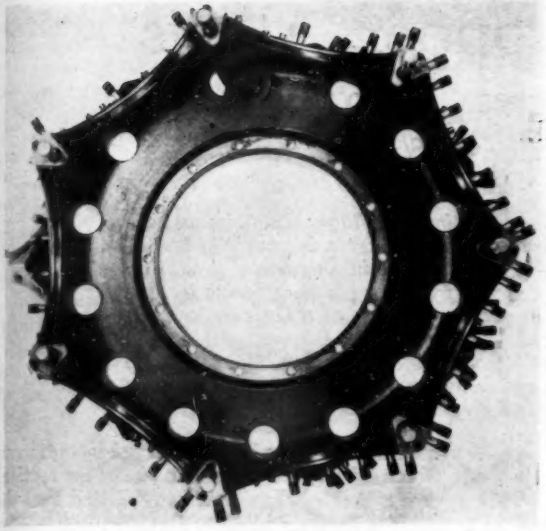

Fig. 13.—Plan of centre-section shown in Fig. 12.

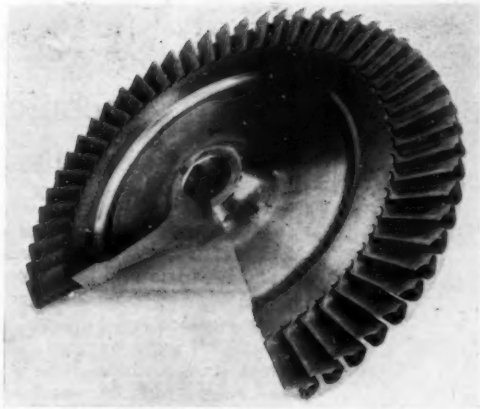

Fig. 14.—Part of exhaust driven turbine wheel, Jumo 207, supercharger.

tempered to a Brinell hardness of 235–260. The studs and pins had been machined from bar stock of 0·5% carbon, 1% chromium-vanadium steel containing 0·07–0·20% vanadium. The studs had been heat-treated to a Brinell hardness of 330–350, and the pins to 300. The connecting studs were cadmium coated on the shanks and exposed ends, whereas the cylinder studs were zinc coated.

The steels used for all the parts were of basic electric quality.

E. Exhaust driven turbine wheel Jumo 207 Supercharger, Ju 86 Aircraft (Item 288)

A general view of a portion of the wheel is shown in Fig. 14, and a detailed drawing in Fig. 15. Results of chemical analyses of the various components are given in Table II. All three parts had been made from 18/8 chromium-nickel steel containing ¾–1% tungsten and 0·5% titanium. The disc and blades had been made as forgings, and the pins from cold worked material.

Mechanical tests on specimens from the disc gave the following results:—

Yield point, tons/sq. in.	..	37·0
Maximum stress ,,	..	45·1
Elongation %	..	43½
Reduction of area %	..	54
Izod ft/lb (transverse to grain flow)	..	34, 67

Brinell hardness tests gave hardness values of 241–248 on the disc and blades, and 332–340 on the pins. The rather high yield point and hardness values of the disc material may be due to the absence of a softening treatment, or to the use of a relatively low softening temperature, although some slight hardening may have occurred as a result of exposure to service conditions.

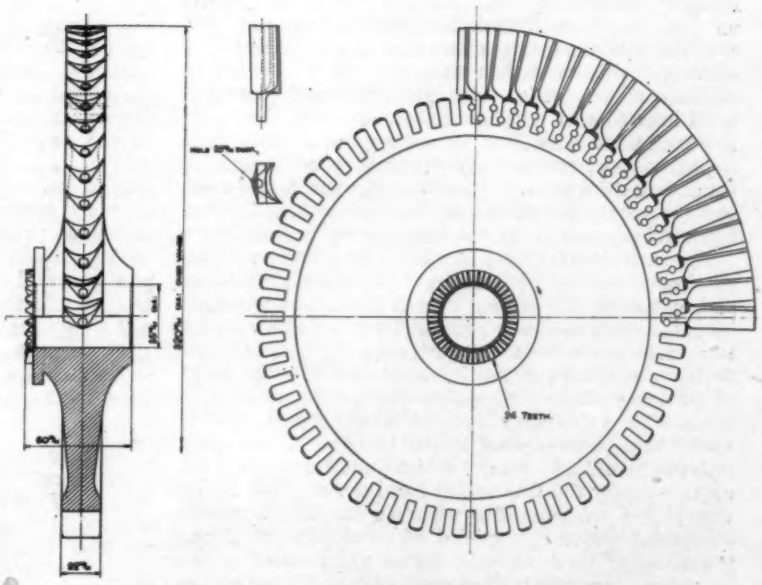

Fig. 15.—Details of exhaust driven turbine wheel, Jumo 207 supercharger.

Correct Melting Point of Alumina Determined

ALUMINA, which is used as an essential ingredient of high-grade spark plug insulators, high-temperature refractories and insulators, in the field of electronics, has a lower melting point than previously supposed. Recent measurements made by R. F. Geller and P. J. Tavorsky, show the melting point of alumina as lying within the range of 2,000 to 2,030° C. This is lower than the value usually quoted, 2,050° C.

Three samples containing over 99·9% of alumina were used in the tests. They were heated in an oxidising atmosphere in an electric furnace, and the temperatures determined by means of an optical pyrometer.

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Copper and Copper Alloys

Technical Progress in 1945

By H. J. Miller, M.Sc.

(*Copper Development Association*)

With the cessation of hostilities and consequent reduction of military requirements non-ferrous metals are being released for peace time application. This is especially true of copper, which has been freed from control and is now available in unrestricted quantities. Although it was necessary to use substitutes for copper for many purposes during the war this material has lost little real ground and its pre-war position as a basic material in practically all industries will be rapidly restored. During the war, however, consumption in Great Britain was over 50% greater than in the pre-war years, thus, there is ample room for the greatly increased use of copper and its alloys in peace time reconstruction and this review directs attention to recent technical progress with this metal and its alloys.

THE present time is perhaps the most important turning point in British industry generally, and this completely overshadows anything that can be said about the copper industry or any of its individual fabricating sections. As copper has played an important part in contributing to wartime industry, the cessation of hostilities and consequent reduction of military requirements has, naturally, much affected all sections of the trade. The primary metal has been freed from control, and has once more become available in unrestricted quantities for all purposes. Since, very approximately, the average wartime consumption in Great Britain was more than 50% greater than in the pre-war years, and the same obtained in America, the bountiful position of the raw material can be judged.

The main task of 1945 has been the commencement of a re-conversion of industry to a peace-time basis, and, naturally, the present time is opportune to review manufacturing methods and efficiency. Taking everything into account, it can justly be claimed that the British non-ferrous metals industries are in a high state of efficiency, having regard to the particular type of trade with which they have to deal. However, it is agreed that there is some leeway to be made up in the replenishment of plant, which matter has been aggravated by the fact that it has been essential in the war period to improvise with the already available equipment. Hence, a period of great activity in the provision of new manufacturing plant can be anticipated, the particular emphasis being on plant required for the manufacture of specialities for peace-time products.

On the whole, copper has lost little real ground during the war period, as instanced by the fact that unsatisfactory experience was obtained with practically all substitutes which, on account of metal-control conditions, were tried for many products, ranging from cartridge cases to cutlery. It is on the score of changes in fashion and the development of new methods of manufacture, that the copper and alloy fabricating industries may have something to fear; conversely, however, these changes often give the chance to exploit new fields and, in some cases, to apply copper-base materials to applications which may not as yet have been visualised.

While, on the whole, there have not been any revolutionary changes in methods, the practice in some sections of the industry has been so modified that it bears, in fact, little resemblance to that of a few years ago. An outstanding example is in casting by continuous methods, which subject is discussed in one of the sections of this review; it must, however, be admitted that the developments in casting practice for standard shapes such as billets and cakes have been taken to a more satisfactory position, and have been more widely applied, than have developments in other fabricating methods. Generally speaking, it is in the questions of size of unit and mechanical lay-out that the changes in fabrication practice are marked, rather than in fundamental method.

From a technical point of view the year 1945 has seen the publication of a considerable amount of interesting work dealing with continuous casting, new methods of rolling, production difficulties, developments of new alloys, the effects of minor elements in the established products, and corrosion problems and other technical matters; activity in the patent field has still been restricted because of censorship.

An account of some of the more important publications on the above and other subjects is given in the following sections.

Continuous Casting

At a recent symposium, Lippert[1], Goss[2], Hazelett[3] Valyi[4] and Williams[5] presented papers on various aspects of continuous casting. Lippert's review was of a general nature, and has revealed the important position which continuous casting has achieved in American industry, especially (*a*) the Junghans-Rossi process for the production of brass billets of large diameter for extrusion; (*b*) the International Nickel Company's process for the production of copper billets and V.C. wire bars in oxygen-free and deoxidised copper; (*c*) the American Smelting and Refining Company's process for the production of deoxidised copper billets. In addition, descriptions were given of the semi-continuous process devised by Aluminium Company of America, which is extensively used for the casting of light alloys, but which does not appear to have been applied to copper-base materials; as well as

1 T. W. Lippert. "Continuous Casting Yesterday and To-day," *Amer. Inst. Min. Met. Eng.*, pp. 2–9, Tech. Pub. No. 1793. (*Metals Technology*, Feb., 1945.)

2 N. P. Goss. "Continuous Casting of Molten Metals: History, Requirements, Metallurgy and Economics," *Amer. Inst. Min. Met. Eng.*, pp. 10–33, Tech. Pub. No. 1793. (*Metals Technology*, Feb., 1945.)

3 C. W. Hazelett, "Improvements in the Direct Casting of Strip Metals," *Amer. Inst. Min. Met. Eng.*, pp. 35–37, Tech. Pub. No. 1793. (*Metals Technology*, Feb., 1945.)

4 E. I. Valyi. "The Soro Process," *Amer. Inst. Min. Met. Eng.*, pp. 37–42, Tech. Pub. No. 1793. (*Metals Technology*, Feb., 1945.)

5 E. R. Williams, "The Williams Process of Casting Metals, "*Amer. Inst. Min. Met. Eng.*, pp. 43–46, Tech. Pub. No. 1793. (*Metals Technology*, Feb., 1945.)

other processes developed by Williams and Goss for the continuous casting of steel, in addition to a consideration of the present position of the Hazelett process for the direct production of copper strip.

While the first three processes mentioned have thus acquired an established position and are in regular use for copper materials, the other processes which have been mentioned—excepting the Alcoa method for light alloys—have not fully emerged from the development stages, as admitted, for example, in the papers by Williams and Goss on steel casting. The Soro process, which should be described as a batch process rather than a continuous casting process, would appear to have been adopted on a small scale only.

Other reviews on continuous casting have been given by Day[6], who proceeded to indicate a possible means for the continuous casting of metal tubes, though no claims whatever were made regarding the application of such methods in actual production, and the description appeared to be based entirely on theoretical considerations.

Other Casting Researches

The improved technique of casting the copper-tin alloys, involving flux treatment fo degassing during melting, followed by slow controlled pouring, has been applied by Winterton[7] in a complete examination of the properties of phosphor bronzes within the range up to 20% tin, and up to 3% phosphorus. The mechanical properties investigated were confined to tensile strength, elongation and Brinell hardness, these being determined on 1 in. dia. chill-cast bars. The strength and elongation results were of a surprisingly high order, it being found that for the straight copper-tin alloys over the range of 7% to 20% tin the strength exceeded 22 tons/sq. in., while with increasing phosphorus additions higher strength properties were recorded; actually, with about 2% phosphorus present and a tin range of 6% to 10%, the strength is of the order of 30 tons/sq. in. The ductility recorded on all specimens was greatly in excess of the normal. These results could be attributed entirely to the controlled melting and casting technique.

Pell-Walpole[8] has also published results on the application of this melting and casting technique in the casting of tin bronzes in chill moulds, studying in particular the effects of phosphorus and aluminium as deoxidants, and noting the effects on density and tensile strength of the chill-cast rods.

George[9] and Smith[10] have considered the question of test-bar casting for production control purposes in foundries, pointing out the necessity of formulating an authoritative procedure to govern testing.

A British technical committee has been giving active consideration to this subject, also, in order to postulate a code of practice.

Precision casting by means of plaster moulds—perhaps better known as the "lost-wax" process—has been studied in particular during the last year by Neiman[11], Dunlop[12], Barnard[13], Morey[14], and Lipson, Markus and Rosenthal[15]. The latter authors studied the properties of leaded gunmetal, 60/40 brass, silicon brass and manganese bronze cast in the form of test pieces of final dimensions, and which were produced by casting at different temperatures and with various cooling and quenching conditions. In Barnard's paper the production of a wide range of brass and manganese bronze castings was described, and attention was drawn to the scope of the process for products which were required to have a high surface finish, close tolerance limits and intricate form. In respect of all these features the method was unique, though it is quite impossible at the present stage to visualise the ultimate competition with normal methods of casting, gravity diecasting or hot stamping.

Metal Working

Hull and Freeman[16] investigated a complaint of apparent laminations in heavy-gauge brass strip required for ammunition purposes, and ultimately concluded that the suspicious nature of the fracture on the sheared edges, reminiscent of laminations, was due to insufficient homogenation of the metal during rolling and annealing. The composition of brasses liable to the defect was found to be limited to the range 65% to 70% copper when hot breaking down was initially employed, but extended over a much wider range when the material was cold rolled throughout.

Underwood[17] and Cook and Larke[18] have undertaken a mathematical analysis of the subject of metal rolling, the latter being particularly concerned with copper, while they have in addition also reported the compression characteristics of a wide range of copper-base materials[19].

Some unusual and interesting methods of copper-base metal-strip production, which have been under development in U.S.A. for a considerable period, have been described during the year[20] [21], though it is as yet quite impossible to visualise the part which the Krause and other special mills may play in future manufacturing procedure, and it is obvious that much further work is required before the methods even achieve a comparable position to the White tube-reducing machine for manufacture of non-ferrous metal tubes.

Some aspects of the production of tubes were considered by Govier[22], while Cotter and Clark[23] have given an excellent review of the fundamentals of extrusion based on a long experience of the extrusion of a wide range of copper-base materials.

6 L. H. Day. "Continuous Casting," *Metal Treatment*, 1945, **12**, 43–48 and 193–199.

7 K. Winterton. "Mechanical Properties of Chill Cast Phosphorus Bronzes," *J. Inst. Metals*, 1945, **71**, 581–588.

8 W. T. Pell-Walpole, "The Effect of Deoxidation Procedure on the Properties of Chill Cast Tin Bronze Melted under an Oxidising Flux," *J. Inst. Metals*, 1945, **71**, 37–44.

9. W. B. George. "Some Causes of Test-Bar Failures in Navy G. and M. Metals," *Trans. Amer. Found. Assoc.*, 1945, **52**, 1175–1184.

10 A. J. Smith. "Test Specimens for Non-ferrous Castings," *Foundry*, 1944, **72**, Dec., 116, 1945, **73**, Jan., 128.

11 R. Neiman. "Precision Casting by the Investment Molding Process," *Trans. Amer. Found. Assoc.*, 1944, **52**, 349–383.

12 A. Dunlop, "Precision Casting by the Lost Wax Process," *Metal Treatment*, 1944–1945, **11**, 247–258.

13 N. B. Barnard. "Plaster Mold Castings," *Materials and Methods*, 1945, **22**, 1085–1089.

14 W. A. Morey. "Industrial Status of Precision Castings," *Amer. Foundryman*, 1945, **8**, Oct. 33–38.

15 S. Lipson, H. Markus and H. Rosenthal, "Precision Cast Copper Base Alloys," *Iron Age*, 1945, **156**, 1 Nov., 46–49, and 8 Nov., 64–73.

16 D. R. Hull, and J. R. Freeman, Jnr. "Phantom Laminations in Brass," *Amer. Inst. Min. Met. Eng.*, Tech. Pub. No. 1790. (*Metals Technology*, Jan., 1945.)

17 L. R. Underwood, "The Rolling of Metals; Theory and Experiment," *Sheet Metal Industries*, 1945, pp. 249–254; 429–436; 613–619; 630; 806–809; 983–991; 1167–1176; 1184; 1360–1366; 1535–1545; 1719–1724; 1736; 1905–1913.

18 M. Cook and E. C. Larke, "Computations of Rolling Load, Torque, and Roll-face Pressure in Metal-strip Rolling," *J. Inst. Metals*, 1945, **71**, 557–588.

19 M. Cook and E. C. Larke, "Resistance of Copper and Copper Alloys to Homogeneous Deformation in Compression," *J. Inst. Metals*, 1945, **71**, 371.

20 J. D. Keller. "Intermittent-acting Mills for Rolling Strip," *Steel*, 1945, **66**, June 18, pp. 108–109; 120, 123 and 126; June 25, pp. 135–136; 139; 173 and 174.

21 P. M. Mueller. "The Krause Mill Reduction Line," *Iron and Steel Engineer*, 1945, **22**, 37–45.

22 W. L. Govier, "Non-ferrous Tube Defects," *Metal Industry*, 1945, **66**, 2–4 and 53–55.

23 W. W. Cotter and W. R. Clark, "The Extrusion Process," *Amer. Inst. Min. Met. Eng.*, Tech. Pub. No. 1850. (*Metals Technology*, Sept., 1945.)

The recovery of copper from spent pickling solutions and wash waters arising in metal fabrication was considered by Southgate and Grindley[24].

Powder Metallurgy Practice

Subsequent to the American Society for Testing Materials and the Electrochemical Society symposia reported in 1944, the American Institute of Mining and Metallurgical Engineers also held a symposium on the subject of powder metallurgy, and the results have become available during the last year[25].

Toeplitz reviewed copper-tin powder products for bearings, while Goetzel and Cox were respectively concerned with hot pressing copper powder compacts, and the production of friction products for brakes and clutches. The latter has also been described by Batchelor[26], and it is obvious that the early success of powdered-metal compacts in friction applications will result in much further experimental work to ascertain the effects of all the many variables. One satisfactory compact was stated by Cox to be made from six raw materials, as follows: copper 67·1%, tin 5·4%, lead 8·9%, iron 7·1%, silica 4·4% and carbon 7·1%; altogether, as many as eight ingredients can go into the making of the compacts. Since variation of the different elements affects such characteristics as coefficient of friction, strength, wear of both the friction material and contacting surfaces, heat development and noise in service, obviously there is room for a great amount of experimentation to find out the best combination. The outstanding feature about these metallic friction materials is their working temperature range of up to 900° C.

Other aspects of powder metallurgy have been given by Hothersall and Gardam[27], Newson[28], Hensel, Larsen and Swazy[29] and Kroll [30], while a well-written and up-to-date German textbook[31] on the subject has also become available.

Corrosion of Copper-Base Materials

Some outstanding work has been published on various aspects of corrosion, the most important individual papers being by Albin[32], Bulow[33], La Que and Clapp[34], Tracy and Hungerford[35], Poluskhin and Shuldener[36]; in addition, there has been a lengthy series of papers on stress corrosion cracking presented at a symposium of the American Society for Testing Materials[37–48].

In the paper by Bulow[33] a wide range of copper-base alloys was exposed to clean flowing sea water for a period of one year, and observations were made on the fouling resulting from the bio-organisms, measurements also being made of loss of weight, depth of pitting and loss of tensile strength. Further tests will subsequently be made on materials after longer periods of exposure, and the conclusions which were presented in the paper were of an interim nature, it being impossible to assess the complete influence of bio-fouling. The greatest amount of bio-fouling was found to occur with the more highly corrosion-resistant materials, whereas copper, straight copper-zinc alloys, naval brass, silicon bronze, low-iron 70/30 cupro-nickel and Admiralty metal were not bio-fouled to any extent. Such materials, naturally, showed a greater impingement attack by the action of the flowing sea water, and in this respect the results conformed with expectations as a result of experience of such alloys in industrial plants.

The subject of bio-fouling as influencing corrosion was also investigated by La Que and Clapp[34], who exposed a wide range of copper-nickel alloys to natural sea water under static conditions. It was observed that the higher nickel alloys became appreciably fouled, whereas the alloys of higher copper contents were not so affected, no fouling being encountered when copper was in excess of 60%. The fouling was related particularly to the formation of two identified organisms, which latter, when dead, resulted in rapid corrosion. It was concluded that for the prevention of fouling, copper should be released in corrosion products at a rate greater than 4·5 mg. to 7 mg. per sq. dm. per day under the static testing conditions. It was pointed out that this rate of release of copper may not hold for circulating conditions, and the conclusions which were reached were advanced in a purely tentative manner, since much further research on this subject was indicated as being necessary.

Tracy and Hungerford[35] tested a wide range of copper alloys by laboratory jet-impingement tests, using synthetic sea water, and supplemented this work by tests in an experimental condenser. The outstanding result of their work was the benefit of iron additions to copper-nickel alloys, the maximum improvement being effected in the range 10% to 20% nickel, though a considerable improvement was also recorded with alloys of the lower nickel content—i.e., 2% to 5% nickel; in the discussion of this paper G. L. Bailey referred to the work undertaken in this country during the last seven years on iron and manganese additions to the copper-nickel alloys ranging from 5% nickel upwards, and which, though not yet reported in detail, confirmed the general conclusions of Tracy and Hungerford.

In the symposium on stress corrosion cracking a great deal of new data was published, and whereas some authors were not satisfied with the mercury-testing procedure for assessing the likelihood of season

24 B. A. Southgate and J. Grindley, "Recovery of Copper from Waste Waters," *Industrial Chemist*, 1945, **21**, 144.

25 "Symposium on Production and Design Limitations and Possibilities for Powder Metallurgy Parts," *Amer. Inst. Min. Met. Eng.*, Tech. Pub. No. 1788. (*Metals Technology*, Jan., 1945.) Containing, amongst others, papers by the following:

W. R. Toeplitz, "Bearings from Metal Powders," pp. 20–27.

C. T. Cox. "Friction Articles from Metal Powders," pp. 42–45.

C. G. Goetzel. "Some Properties of Sintered and Hot-pressed Copper-tin Compacts," pp. 58–71.

26 C. S. Batchelor, "Metal Powder Friction Materials," *Metals and Alloys*, 1945, **21**, 991.

27 A. W. Hothersall and G. E. Gardam, "Preparation of Copper Powder by Electrodeposition," *J. Electrodepos. Tech. Soc.*, 1945, **20**, 61–68.

28 J. E. Newson. "Power Metallurgy," *Inst. Mech. Eng.*, preprint, 1945.

29 F. R. Hensel, E. I. Larsen and E. F. Swazy, "Notes on Copper-base Compacts and Certain Compositions Susceptible to Precipitation-hardening," *Amer. Inst. Min. Met. Eng.*, Tech. Pub. No. 1810. (*Metals Technology*, Aug., 1945.)

30 W. J. Kroll. "Production of Metal Powders," *Electrochem. Soc.*, 1945, preprint.

31 R. Kieffer and W. Hotop, "Powder Metallurgy," published by Springer, Berlin, 403 pp.

32 J. Albin, "Marine Tests Rate Alloy Performance," *Iron Age*, 1945, **156**, July 26, 62–67, 82.

33 C. L. Bulow. "Corrosion and Bio-fouling of Copper-base Alloys in Sea Water," *Electrochem. Soc.*, 1945. Preprint 87–26.

34 F. L. La Que and W. F. Clapp. "Relationships Between Corrosion and Fouling of Copper-nickel Alloys in Sea Water," *Electrochem. Soc.*, 1945. Preprint 87–15.

35 A. W. Tracy and R. L. Hungerford. "The Effect of the Iron Content of Cupro-nickel on Its Corrosion Resistance in Sea Water," *Amer. Soc. Test. Mat.*, 1945. Preprint A.2.

36 E. P. Poluskhin and H. L. Shuldener, "Corrosion of Yellow Brass Pipes in Domestic Hot-water Systems—a Metallographic Study," *Amer. Inst. Min. Met. Eng.*, Tech. Pub. No. 1742. (*Metals Technology*, Oct., 1944.)

37 T. A. Read, J. B. Reed and H. Rosenthal. "The Mechanism of the Season Cracking of Brass," Joint A.S.T.M.—A.I.M.E., "Symposium on Stress-corrosion cracking," 1944.

38 G. Edmunds. "Season Cracking of Brass," Joint A.S.T.M.—A.I.M.E., "Symposium on Stress-corrosion Cracking," 1944.

39 G. Edmunds, E. A. Anderson and R. K. Waring, "Ammonia and Mercury Stress-cracking Tests for Brass," Joint A.S.T.M.—A.I.M.E., "Symposium on Stress-corrosion Cracking," 1944.

40 T. C. Wilson, G. Edmunds, E. A. Anderson and W. M. Peirce, "Effect on Season Cracking of Alloy Additions to Cartridge Cases," Joint A.S.T.M.—A.I.M.E., "Symposium on Stress-corrosion Cracking," 1944.

41 H. Rosenthal and J. Mazia. "Residual Stress in Calibre 0.30 Cartridge Cases," Joint A.S.T.M.—A.I.M.E., "Symposium on Stress-corrosion Cracking," 1944.

cracking and advocated an ammonia atmosphere test, the general conclusion seemed to be that the mercury test afforded an accurate guide. Gohn and Arnold[45] stressed various copper-alloy materials by bending methods when in the presence of mercury, their experience in telephone and related applications completely confirming the reliability of mercury stress cracking methods. They reported that the yield strength is approximately the safe limit for stress which may be imposed in the presence of mercury or in service; it was however, inadvisable to design up to this limit, and a factor of safety should be introduced to offset the possible effects of any abnormalities which could result in stress concentration.

Properties of Copper

It has formerly been the view that carbon shows no solubility whatever in copper, but in recent work by Bever and Floe[49] it has been found that there is a solubility of 0·003% at 1700° C., falling to 0·0001% at 1100° C.; the same authors also found a similar solubility of carbon in copper-tin alloys. Such quantities, although appearing to be of an insignificant order, were nevertheless sufficient to contribute to gas porosity.

Smart and Smith[50] have investigated the effects of phosphorus, arsenic, sulphur and selenium on the conductivity and annealing characteristics of high-purity copper, of both oxygen-free and tough-pitch types. Their results indicated slight deviations from the formerly accepted values, though the differences were not of an outstanding order. It was reported that the softening temperature as determined by short-time laboratory tests was raised from 140° C. for high-purity copper to about 300° C. for copper containing either 0·01% tellurium or 0·02% phosphorus; 0·01% arsenic raised the figure to about 200° C. only.

Cook and Davis[51] have investigated the influence of phosphorus on the mechanical properties and welding characteristics of both arsenical and non-arsenical copper. Up to 0·14% phosphorus, which was the maximum added in either series, an increase of the phosphorus content gave slight progressive increases of both the work-hardening rate and the annealing temperature. With temperatures, above 600° C. a marked increase in rate of grain growth was experienced with the higher phosphorus materials, particularly in the arsenical series. The welding tests indicated that the best results were achieved with between 0·05% and 0·10% phosphorus present in the parent metal, a series of welded joints made on $\frac{1}{4}$ in. thick material showing properties of 13 tons/sq. in. tensile strength, and 25% to 30% elongation. A further conclusion reached in further welding trials was that the filler rods should also carry 0·05% to 0·10% phosphorus.

Found[52] has published a study of internal friction in single crystals of copper and some other materials.

Properties of Copper Alloys

Arising from the availability of high-purity electrolytic manganese the re-investigation of various alloy groups has proceeded, and during the year publications have been concerned with the copper-manganese group[53 54], the copper-manganese-nickel group[55] and the copper-manganese-zinc group[56 57]. The copper-manganese-nickel alloys have interesting precipitation-hardening characteristics, and the alloys within the range 52% to 60% copper, 20% to 24% manganese and 20% to 24% nickel have outstandingly high mechanical properties, namely, up to 80 tons/sq. in. for strip material in the fully heat-treated condition, and which it can therefore be seen compare closely with those of beryllium copper. Some commercial use of alloys of this type has been announced, the particular function being for various fabricated springs in wire and strip forms.

The copper-nickel-phosphorus series of precipitation-hardening alloys has been investigated by Blazey[58], who was concerned particularly with the influence of arsenic and bismuth present as impurities; he reported that arsenic did not exert any very significant effect, but bismuth had an embrittling effect which could, however, be overcome at room temperature by a sufficient excess of phosphorus. A recent U.S. patent[59] which has been granted on the copper-nickel-phosphorus alloys is concerned with temper-hardening followed by cold working to the extent of at least 70% to give a further improvement of the properties; the alloy was claimed to be particularly suitable for spring applications in view of the high endurance limit, good creep and relaxation properties, resistance to stress corrosion cracking, and high softening temperature.

Another heat-treatable alloy which has formed the subject of a recent patent is based on the copper-nickel-tantalum series within the compositional range of 10% to 50% nickel, 0·5% to 5% tantalum, remainder copper, with the probable presence of some other elements[60]; such alloys are of particular interest because of the high temperatures required for precipitation, namely, in the range 600° C. to 800° C. Claims have been made in respect of the copper-nickel-silicon alloys to which manganese up to 0·5% is added to enable cast products to be hardened by single-stage heat-treatment[61]. Other patents are in respect of the copper-chromium alloys containing zinc and sulphur[62],

42 H. Gisser. "Protective Resin Films on Cartridge Brass," Joint A.S.T.M.—A.I.M.E., "Symposium on Stress-corrosion Cracking," 1944.
43 J. W. Mitchell. "The Role of Smokeless Powder in the Season Cracking of Small Arms Ammunition," Joint A.S.T.M.—A.I.M.E., "Symposium on Stress-corrosion Cracking," 1944.
44 G. Sachs, G. Espey and S. M. Clark. "Factors Influencing the Stress-cracking of Brass Cartridge Cases," Joint A.S.T.M.—A.I.M.E., "Symposium on Stress-corrosion Cracking," 1944.
45 G. R. Gohn and S. M. Arnold. "The Stress-corrosion Properties of Some Non-ferrous Sheet Metals," Joint A.S.T.M.—A.I.M.E., "Symposium on Stress-corrosion Cracking," 1944.
46 A. L. Jamieson and H. Rosenthal. "The Aqua-Ammonia Test," Joint A.S.T.M.—A.I.M.E., "Symposium on Stress-corrosion Cracking," 1944.
47 C. L. Bulow. "Stress-corrosion Testing of Copper-base Alloys," Joint A.S.T.M.—A.I.M.E., "Symposium on Stress-corrosion Cracking," 1944.
48 T. A. Read, H. I. Fusfield and S.W. Kitchen. "Sonic Testing for Cracks," Joint A.S.T.M.—A.I.M.E., "Symposium on Stress-Corrosion Cracking," 1944.

49 M. B. Bever and C. F. Floe, "Solubility of Carbon in Molten Copper," *Amer. Inst. Min. Met. Eng.*, Tech. Pub. No. 1802. (*Metals Technology*, Sept., 1945.)
50 J. S. Smart and A. A. Smith. "Effect of Phosphorus, Arsenic, Sulphur and Selenium on Some Properties of High-purity Copper," *Amer. Inst. Min. Met. Eng.*, Tech. Pub., No. 1807, (*Metals Technology*, Sept., 1945.)
51 M. Cook and E. Davis. "Effect of Phosphorus on the Properties and Welding Characteristics of Arsenical and Non-arsenical Copper and on Copper-Silver Alloy Filler Rod," *Trans. Inst., Welding*, 1945, **8**, 19–27, 29.
52 G. H. Found. "Internal Fraction of Single Crystals of Brass, Copper and Aluminium," *Amer. Inst. Min. Met. Eng.*, Tech. Pub. No. 1804. (*Metals Technology*, June, 1945.)
53 R. S. Dean, J. R. Long, T. R. Graham, E. V. Potter and E. T. Hayes "The Copper-manganese Equilibrium System," *Trans. Amer. Soc. Metals*, 1945, **34**, 443–463.
54 R. S. Dean, E. V. Potter, J. R. Long and R. W. Huber. "Properties of Transitional Structures in Copper-manganese Alloys," *Trans. Amer. Soc. Metals*, 1945, **34**, 465–480.
55 R. S. Dean, J. R. Long, T. R. Graham and C. W. Matthews, "Age-hardening Copper-manganese-nickel Alloys," *Trans. Amer. Soc. Metals*, 1945, **34**, 481–502.
56 R. S. Dean, J. R. Long, T. R. Graham and C. W. Matthews, "A White High Manganese Brass," *Amer. Inst. Min. Met. Eng.*, Tech. Pub. No. 1813. (*Metals Technology*, June, 1945.)
57 R. S. Dean, J. R. Long, T. R. Graham and A. H. Robertson, "The Alpha Solid Solution Field of the Copper-manganese-zinc System," *Amer. Inst. Min. Met. Eng.*, Tech. Pub. No. 1836. (*Metals Technology*, June, 1945.)
58 C. Blazey, "The Influence of Arsenic and Bismuth on the Mechanical Properties of Copper-nickel-phosphorus Alloys," *Proc. Austral. Inst. Min. Met.*, 1944, No. 133, 65–81.
59 D. K. Crampton, M. Burghoff, H. L. Burghoff and Chase Brass and Copper Company, U.S. Patent 2,375,285.
60 American Brass Company and C. S. Smith, British Patent 569,408.

and the copper-nickel-phosphorus and copper-beryllium-cobalt-silicon series containing sulphur[63] to promote free machining characteristics.

It has been claimed that the addition of 0·5% of either nickel or cobalt to brasses, which carry arsenic or antimony within the range 0·1% to 1%, will overcome the harmful effects resulting from the presence of the latter; at the same time, brasses of outstanding resistance to dezincification are produced[64].

In work by Fink and Hutton[65] efforts were directed to the production of high-cobalt-content alloys which, however, proved abortive, though some interesting observations were made of the lower cobalt range, which were quite malleable, as typified by 3% cobalt, 97% copper.

Various aspects of beryllium copper have been considered by Slagle[66] and Harker and Murphy[67], the interest of the latter being a correlation of the precipitation-hardening effect with the structure as revealed by the electron microscope. Hunt and Taylor[68] also included beryllium copper amongst other copper alloys in a review of electrical contact springs.

Wilson and Brick[69] have made a theoretical study of the crystallographic structure of 70/30 brass, and of copper subjected to various methods of fabrication at the penultimate annealing, final rolling and final annealing stages, this investigation being undertaken with the object of correlating crystallographic structure with directional mechanical properties, and tendency to form wavy-topped cups on forming and drawing.

Joining Practice

Several papers dealing with practically all the many types of joining processes have appeared in the last year, and reference can only be made to a few of the more important of these.

The furnace method of joining steel by copper, brasses and silver solders, has received further publicity by many advocates, and, while nothing of an outstanding character has appeared, mention might be made of the work of King[70] on the influence of surface finish; the findings were that surface finish was without significant influence on the shear strength of copper-brazed joints of the capillary type made on steel tubes. The application of induction heating methods for the silver soldering of steel has been described by Weed[71] Hjermstad[72], and Setapan[73], though the method is perhaps not sufficiently flexible for wide application.

The silver soldering of both copper and steel has been studied by Berman and Harrington[74], based on the fractures obtained on butt-jointed specimens, while, in addition, many descriptions have been given of industrial applications in aircraft and other industries. It is obvious that silver soldering has experienced a much extended field of application during the war period.

An interesting application of the low melting point copper-phosphorus alloys is for the production of clad metals[75], in which the basic strip materials have sandwiched between them a thin foil of the copper-phosphorus alloy containing up to 4% phosphorus, the assembly afterwards being heated in a non-oxidising atmosphere at 645° C to 780° C., and submitted to pressure to consolidate the bond.

The metallic arc-welding of copper and of copper alloys has been surveyed by Lawrence[76], this practice being performed to a much wider extent in U.S.A. than in this country. A further comprehensive review of welding literature, with particular reference to the welding of dissimilar metals, has been given by Spraragen and Rosenthal[77].

Reference was made earlier in this review to the work of Cook and Davis[51] on the oxy-acetylene-welding of copper by the usual British procedure, arising from which it was advocated that the phosphorus content of both parent metal and filler rod should be controlled within limits of 0·05% to 0·10%.

61 Langley Alloys, Ltd., British Patent 570,727.
62 Enfield Rolling Mills Ltd., and J. Sykes, British Patent 567,052.
63 Enfield Rolling Mills Ltd. and J. Sykes, British Patent 566,949.
64 J. Stone and Co., Ltd., G. T. Callis and A. J. Murphy, British Patent 568,665.
65 C. G. Fink, J. L. Hutton and L. Delisle, "Copper Cobalt Alloys," *Trans. Electrochem. Soc.*, 1944, **85**, 119–122, 123–131.
66 G. H. Slagle. "Beryllium Copper—Some Processing Characteristics," *Metals and Alloys*, 1945, **22**, 731–734.
67 D. Harker and M. J. Murphy. "A Study of Age-hardening Using the Electron Microscope and Formvar Replicas," *Amer. Inst. Min. Met. Eng.*, Tech. Pub. No. 1811. (*Metals Technology*, June, 1945.)
68 L. B. Hunt and H. G. Taylor, "Electrical Contact Springs," *Jour. Inst. Elec. Eng.*, 1945, **92**, Pt. III, 38–44.
69 F. H. Wilson and R. M. Brick. "Textures, Anistropy and Earing Behaviour of Brass," *Amer. Inst. Min. Met. Eng.*, Tech. Pub. No. 1803. (*Metals Technology*, June, 1945.)
70 N. L. King. "Shear Strength of Copper Brazed Joints," *Iron Age*, 1945, **155**, April 5, 71–73.
71 J. P. M. Weed. "Silver Brazing by Induction Heating," *Welding Jour.*, 1945, **24**, 553–556.
72 H. V. Hjermstad, "Induction Brazing and Soldering," *Iron Age*, 1945, **156**, Aug. 9, 56–60.
73 A. M. Setapan, "Silver Alloy Brazing: Use of Electric Induction for High-speed Heating," *Met. Industry*, 1945, **66**, 180–183 and 198–200.
74 F. Berman and R. H. Harrington, "Fracture Studies of Soldered Joints," *Trans. Amer. Soc. Metals*, 1945, **34**, 143–155.
75 M. Cook, G. Parker and I.C.I. Metals, Ltd., British Patent 569,784.
76 H. Lawrence, "Metallic Arc-Welding Electrodes," *Welding Jour.*, 1944, **23**, 1159–1167.
77 W. Spraragen and D. Rosenthal, "Welding of Dissimilar Metals," *Welding Jour.*, 1945, **24**, 65s.–85s.

Platinum Metals

PLATINUM metals contributed greatly to the winning of the war, large quantities being used in aeroplane spark plugs, for contacts in magnetos and in numerous instruments, including airplane flight controls, bombing equipment, and computing apparatus. For electronic devices, including radar, platinum and platinum clad grids were required in high-frequency transmission tubes. Platinum alloys were used as catalysts in manufacturing nitric acid, for explosive production; and platinum alloy spinnerets and bushings for glass fibres produced for varied war purposes. Insoluble platinum anodes produced the perchlorates, peroxides and other chemicals obtained by anodic oxidation.

Instruments used in communications, navigation, automatic controllers, and in measuring and recording devices of many kinds utilised platinum metals as well as the electrical, mechanical and corrosion resisting properties of platinum.

Long valued primarily for adornment purposes, the platinum metals have demonstrated their merit and economy for industrial uses, enabling better quality chemicals to be produced at lower costs; equipment to give better service with less maintenance; and greater precision and reliability in measuring instruments and automatic controllers or recorders. They have replaced base materials in many cases. Current research and development are aimed at the continued improvement of platinum alloys and the expansion of the platinum metals in world markets.

Noral Alloys

THE Northern Aluminium Company, Ltd. announce that its alloys will henceforth be designated by the name of "Noral," thus identifying the Company's trade mark with the materials which it produces.

The Manufacture of Seamless Steel Tubes*

By J. W. Jenkin, Ph.D., B.Sc., A.R.I.C., F.Inst.M.

Director of Research, Tube Investments, Ltd.

The application of seamless steel tubes in many industries has made great progress in the last twenty years. Tubular products are especially useful for conveying gases or liquids and metallurgical developments have contributed to the improvement of steels for special seamless tubes for many industries, including the oil-refining, chemical, and high-pressure steam industries; they are also being used in increased quantities for structural purposes because they combine maximum stress carrying capacity with minimum weight. Practically all the regular carbon and alloy steels may be used in the seamless process; the chromium steels containing from 1 to 3 per cent. chromium and numerous other alloyed steels containing chromium with additions of such elements as molybdenum, nickel, manganese, silicon and titanium, are included in those successfully processed. Hot rolling operations provide the bulk of seamless tubes for ordinary requirements, but, when greater accuracy, high physical properties, better surfaces, thinner walls and small diameters are required, the tubes are cold drawn as a finishing operation. The various operations in seamless steel tube manufacture are described.

COLD WORK

For closer accuracy of dimensions, smoother surface and (where necessary) smaller sizes, the hot finished tube, then called a "hollow," proceeds to subsequent operations of cold work, in particular, cold drawing.

Cold Drawing

This is a process that accounts for literally millions of feet per week. It consists essentially in pulling a cold tube through a die, the end of the tube being pointed, or "tagged" as it is called in the trade, for the purpose. The cold drawbench in simplest outline consists of a horizontal bench with the die mounted at about the middle. One half of the bench supports the ingoing tube, generally on a mandrel that is anchored adjustably at the far end. An endless chain on the outcoming side of the die travels in a runway along the bench, over a driving sprocket, and back under the bench towards the die. A device known as a "dog" travels on wheels on the bench over this chain; it is called a dog because it has teeth that bite the tag end of the tube, it has hind legs that can be inserted in the links of the chain, thereby pulling the tube through the die, and the lever that serves to engage the hook in the chain stands up like a dog's tail; close to the head of the dog is another lever that sticks up like a dog's ears, this being the one that actuates the biting of the tag end of the tube by the dog's jaws.

There are three ways in which a tube may be cold drawn. The tube may be empty when it is pulled; this is pure sinking, and the stretch is accompanied by a thickening of the wall since there is nothing to support the bore. More usually a plug is held in the orifice of the die, which means inserting it into the tube before it is drawn, and the size of the die and plug govern respectively the outside and inside diameters of the outcoming drawn tube.

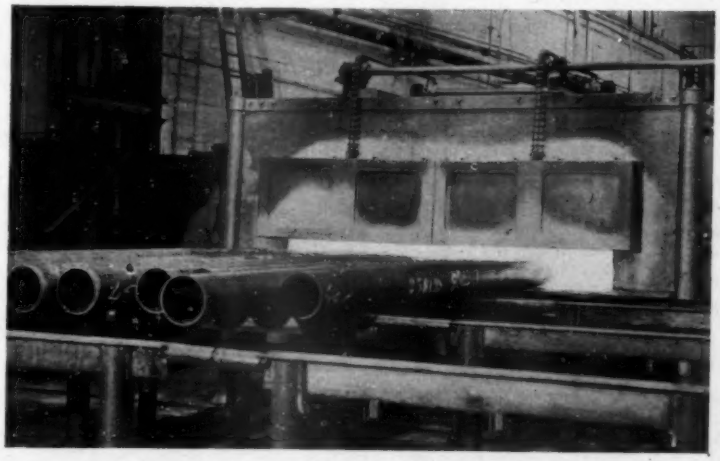


Fig 20.—Heating the ends of large tubes for "nozzling."

Alternatively to plug drawing, a bar may be inserted into the tube and gripped by the dog, so that both tube and bar are pulled through the die together; behind the die the reduction in diameter and thickness of the tube causes a relative movement of the tube back along the bar. Bar drawing permits greater reductions of area per pass, there being less friction on the bore, but of course the tube is hard down on to the bar and has to be reeled off by a cross rolling operation something like that described previously in connection with reeling hot finished tubes off push bench mandrel bars.

So the heavier reduction in bar drawing is offset by the need for an additional operation, and by far the great majority of cold drawn tubes are pulled over a stationary plug, which is a short stem screwed into a long mandrel that is held by a back stop at the far end on the ingoing side of the bench.

The three methods of cold drawing are therefore: (1) sinking, (2) plug drawing, (3) bar drawing, of which the second is by far the most generally practised. The length of the bench will necessarily be about twice that of the longest tube to be drawn; benches have been known on which tubes could be drawn to a length of 60 ft., but this is abnormal; the average length is more like 20 or 30 ft. Dies and plugs are of straight 1% carbon or alloy steel, appropriately heat treated, and wherever practicable are chromium

* Contd. from page 64, Dec. 1945 issue.

Fig. 21.– " Nozzling " :] reducing the end of a tube preparatory to cold drawing.

Fig. 23.—" Tagging " hammer for pointing the ends of tubes for cold drawing.

plated. Except where ruled out by size considerations, inset tungsten carbide dies are employed.

In cold drawing small tubes it is common practice to have two mandrels in use alternatively, the idle plug being examined and loaded, i.e., threaded, with another tube-while one tube is being drawn. A device at the far end of the bench automatically ensures that the particular mandrel in use is accurately aligned in the direction of the pull. Modern benches are highly mechanised, especially, for instance, large benches that can exert a pull of 120 tons; in such equipment the loading and unloading, the locating of the plug in the right position in relation to the die, the return of the dog, and the engagement of the hooks in the chain, are all done mechanically with very little manual labour. One such bench in this country can draw tubes 9 in. outside diameter and 28 ft. long.

Within these three methods of drawing several changes can be rung. To save material in tagging, particularly with large tubes, the end of the tube may be merely nozzled, that is closed with a fairly sharp shoulder sufficiently to allow the insertion of a loose pin, the head of which takes the thrust against the inside of the nozzle, and the stem of which protrudes far enough through the die to be gripped in the jaws of the dog.

Nozzling can with advantage be employed for large tubes, say, 8 in. to 10 in. outside diameter when drawn on a bar; here " drawing " is hardly a proper term since the mandrel with the nozzled tube on its end is pushed through the die, and the tube is then reeled off its bar.

Since the essential part of all these processes is relative movement of tube and tools, it is more convenient on very large tubes up to, say, 26 in. diameter to move the die over the tube, the latter being mounted on a bar of a diameter corresponding to the desired bore of the drawn tube. Since the tube then has to be reeled off, the finished

Fig. 22.—Typical "nozzled " ends, for use with a pulling pin as in Fig. 21.

Fig. 24.—Typical " tagged " ends, by which the tube itself is gripped for cold drawing.

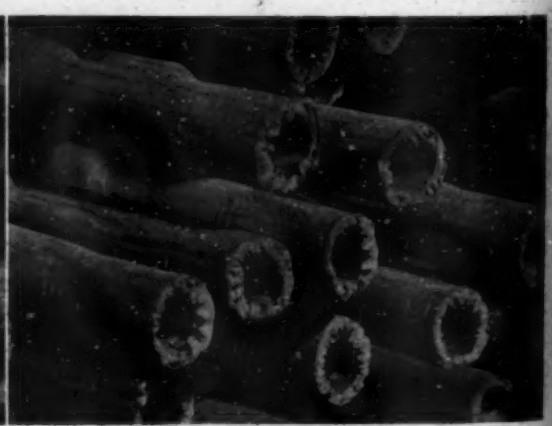


Fig. 25.—Cold draw bench "dog" gripping a pulling pin engaged in the "nozzled" end of a tube.

bore is slightly larger than the diameter of the bar.

Pickling

One of the most important aspects of cold drawing is lubrication, so the surfaces of the tube require preparation to take the lubricant. This means that hot rolled tubes must be pickled. Tubes that are to have a second and subsequent passes, and have therefore been annealed for redrawing, must have their annealing scale removed in a similar way. One might say that annealing for subsequent operations could quite well be done in controlled atmosphere furnaces to minimise or eliminate scaling. This is sometimes done, but the surface is still too smooth to take the lubricant, so pickling must be resorted to; naturally since the object is then a mere roughening of the surface with little or no scale removal, pickling times can be short.

Pickling is, for the most part, done in sulphuric acid, the vats, or "boshes" as they are called, being heated by live steam. The action of the sulphuric acid, as is well known, is to dissolve the inner layer of scale, the FeO, and the outer layers fall off or are broken off by the evolution of hydrogen. This means not only an accumulation of iron in solution but also of undissolved sludge in the bosh. The life of a pickle bosh is limited by the accumulation of this sludge, which may cause dirty bores, rather than by the increase in the iron content or the decrease in the percentage of free sulphuric acid. It is usual to start with 6 to 10% of sulphuric acid, and it is generally found necessary to discard the bosh when it still contains perhaps 1½% of acid or even more, and the iron figure approaches 7%.

More important than the composition of the liquor is the temperature and state of agitation. One can get more life out of a bosh by raising the temperature from, say, 60° C. to 70 or 80° C. than by adding more acid. Efficient agitation may well reduce pickling times by a half. With tubes, agitation is necessary in order to flush out the bores and ensure absence of sludge.

In modern plants bundles of tubes are supported on chains that immerse and withdraw the tubes repeatedly. The chains, anchored at each end, pass over sprockets centrally placed above and between two boshes so that as a reciprocating motion is applied to the sprockets the tubes are immersed alternately in each bosh. This avoids any shielding due to continuous contact between the tubes, because they roll over each other as the chain carries them in and out of each bosh. In older plants this repeated lifting is done by hand or by crane, allowing the liquor to run rapidly out of the tubes. In order to make sure that pickle liquor flows through the tubes it is necessary that the tag be hollow, or if it is not, then a hole is punched in the tag end to avoid air locks. Hydrochloric acid is also extensively used, particularly for smaller tubes, when it appears to give cleaner bores. In that case, of course, steam heating is unnecessary.

Vats or boshes are of varied con-

Fig. 26.—A small tube being cold drawn. (The "dog" is gripping a "tagged" end).

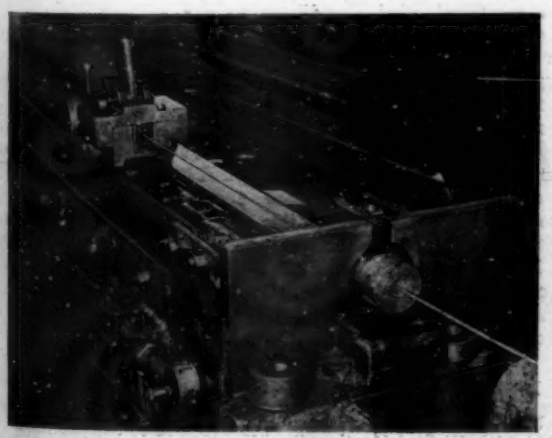


Fig. 27.—Hypodermic needle tubing being cold drawn through a die and coiled like wire on a drum.

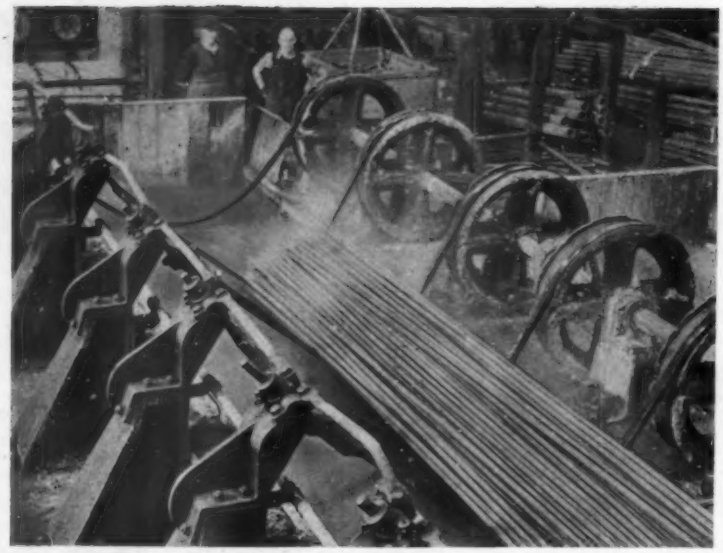


Fig. 28.—Mechanical pickling arrangement for intermittent immersion in acid.

struction, from older types of bricks laid in molten sulphur to more modern ideas of steel tanks lined with rubber. Brick boshes need lining with timber to prevent the tubes damaging the bricks. After pickling, the tubes must be washed in hot water and the spent pickle neutralised, but of course much of this pickling technique is common to several industries and needs no special mention here.

Lubrication

A governing factor in cold drawing, as mentioned above, is lubrication, and if only one can prevent true contact between the tube and tools, it is surprising what punishment steel will stand. Pride of place goes to a common brown soap, in solution (or perhaps one should say emulsion) in hot water, into which rusted tubes are dipped. Rust seems to assist, but this is most probably a mechanical effect of roughening the surface and forming a key for the lubricant, rather than a chemical effect such as the formation of an iron soap.

There are those who claim that rust is not essential, but in the majority of instances the time factor makes rusting inevitable. That a matt surface is necessary is demonstrated by the fact that a smooth cold drawn tube that is bright annealed is still too smooth to hold the lubricant and needs to be roughened by lightly pickling. Certainly the soap film must be quite dry, or else its film strength will be so low that it readily breaks, when the tube and tools will be in intimate contact at a high pressure, and seizure or "pick-up" occurs.

Oil is used for fine finishing passes when a relatively light amount of reduction is imposed. There are several efficient proprietary lubricants, and the standard mixture in America is tallow, flour, and water.

Although the tube is quite cold when it enters the die, the work done raises the temperature so that on the outcoming side it soon gets too hot to touch; for efficient lubrication therefore the desideratum is some substance that will not lose its film strength too soon with rise of temperature.

Metallic lubricants are not unknown: a copper coating applied simply by dipping into an acidified copper sulphate solution used to be common, but it has practically died out; lead coating applied by dipping into molten lead is quite successful, even to economising on intermediate anneals, but the problem of its subsequent removal restricts its use to stainless steels that are not attacked by nitric acid. Zinc or cadmium can be applied to the outside only, by electrodeposition, so are limited to drawing on a bar as distinct from drawing on a plug. In drawing stainless steel tubes, the common lubricant is lime, applied as a powder by hand as the tube enters the die; this dilutes the soap or graphite on the tubes and minimises carbon pick-up in any subsequent annealing.

The die shape must be such that it does not wipe the lubricant off. It generally takes the form of a simple radius, but where the diameter drop is great compared with the reduction in wall, a relatively long lead-in is desirable; in the extreme case of hollow sinking a champagne-bottle-neck contour assists in getting the lubricant right through the die. Under such conditions a 3 in. outside diameter can be sunk to 1½ in. outside diameter without trouble. Strangely enough it is not essential in such a case even to remove the scale. A heavy sink, however, leaves the tube in a state of considerable internal stress, and one has to anneal immediately to avoid spontaneous splitting from end to end.

This question of residual internal stress is important and complicated: it even varies with the shape of the die with constant starting and finishing sizes. Most tubes as drawn will spring open or shut when a ring cut from them is slotted, just as longitudinal strips will bow one way or the other, and there are bound to be unpredictable variations in residual stress due to straightening. These stresses also affect change of shape on subsequent machining. No tube comes off the drawbench quite straight, on account of the combined effect of lack of straightness from hot rolling or a previous anneal, eccentricity, improper alignment of the die, and similar factors.

Straightening

Large hot finished tubes can be straightened by supporting them on blocks and bending them in the reverse curvature to a controlled degree by a hydraulic ram operating vertically between the supports. The same principle is applied to small cold drawn tubes in short lengths with the added advantage that the operator can readily move both tubes and supports by hand and control the pressure applied until he sees by dial gauges that the straightness is within prescribed limits. Operators on this work acquire a remarkable skill and rapidity.

A common but perhaps less precise method applied to all sorts of tubes is to pass them through a reeling machine, a cross rolling process between concave rolls, not convex, and set at an angle to cause the tube to spin and move forward at the same time. The use of concave rolls provides line contact between the rolls and the tube. Just as a piece of wire can be straightened on a wooden bench by pulling it through a series of nails slightly staggered as to the positions in

which they are driven into the bench, so a tube can be straightened by "snaking" it in an appropriate machine. Several concave reeler rolls may thus be used in succession, causing the tube to spin as it travels forward, bearing against each successive concave roll one side or the other. Similarly, in a non-rotating process one may use grooved rolls, familiar to bar and rod rollers, but staggered instead of being two-high anywhere.

In spite of these mechanical refinements, a lot of hand straightening by eye may be seen in any cold drawing mill; the tube is inserted in wooden blocks at about eye level, and the operator turns it and presses on the end as his experience teaches him. It is remarkable what a high degree of skill these operators have, and there are those who claim that no machine can equal them.

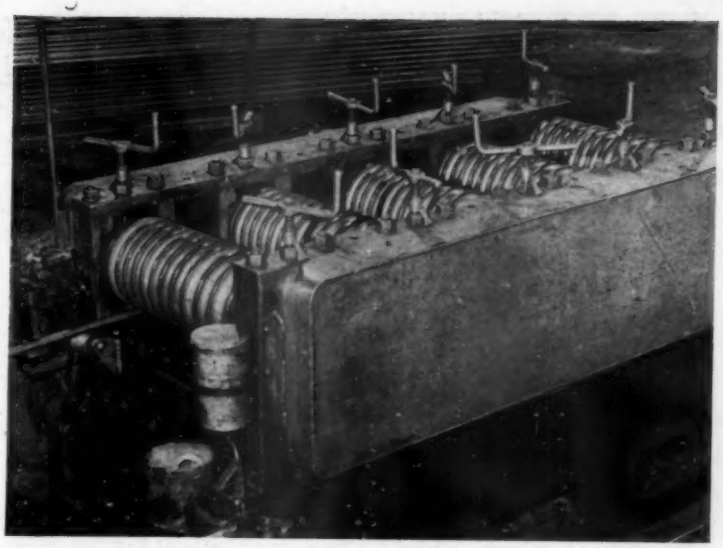


Fig. 29.—Nine-roll straightening machine for various sizes of tubing.

Annealing

Whatever form the drawn tube may take it has to be softened for any further cold work. For the low carbon steel that forms the bulk of the tonnage, this is just a sub-critical anneal at 650–700° C. This is done in batch type furnaces fed in modern works by charging machines, which carry the load in on arms that enter into longitudinal grooves in the bed of the furnace. Alternatively it is done continuously in controlled atmosphere furnaces, electrically heated, or in one interesting variation in a gas-fired furnace in which the burners are tangentially disposed around the moving tubes, and each tube pushes the one ahead of it, the rear ones being driven by engagement in an endless chain on the entry side. The tag end of each tube fits into the open end of the one ahead of it, and the result is a minimum of scale in the bore. Normalising is of course employed whenever necessary and in many plants is done continuously. Heating in larger tubes is frequently employed to minimise scaling when controlled atmosphere furnaces are not available.

Heavy Reductions

The reduction of area per pass in plug drawing is generally 25% or 30%; in bar drawing it can be as much as 40%. It is undesirable to apply less than 15% in view of the likelihood of excessive grain growth in a subsequent low temperature anneal. But reduction of area is an incomplete measure of the work done, for with a hollow body mere reduction of area cannot recognise the relation between sink and draft, i.e., the amount taken off the outside diameter compared with the reduction in thickness. Moreover, there are methods of applying the work so as to minimise the effects of residual internal stresses, and so give very heavy reductions and yet preserve some ductility in the tube.

In connection with hot working, reference has been made to the principle of the pilger rolls, in which the hot tube advances step by step against the tapering action of the rolls kneading it on to the mandrel. This can be done cold, in which case the housing carrying the tapered grooved rolls may move backwards and forwards along the tube, instead of the hot tube moving backwards and forwards in relation to a stationary housing. In cold pilgering the bore is generally supported by a tapered mandrel, and the reciprocating motion of half-rolls with tapered grooves irons the tube out to a smaller o.d. and thinner wall, the tube being fed forward from the rear a fraction of an inch at each stroke. This gives spectacular reductions of cross sectional area such as 80%, equivalent to several cold drawing passes of the conventional type.

The applicability of this process is a matter of economics, so its success will vary not only from one country to another but from works to works. Some claim is made in cold pilgering for correction of any eccentricity that might have been imparted by irregular heating of the original billet or maladjustment of piercing mills, but experience suggests that correction of eccentricity in cold work depends on the total amount of work and not on how it is done; in any case it is not substantial.

One can, of course, go on drawing and annealing to quite small dimensions, but there comes a time when internal support by plug or mandrel becomes out of the question. The smallest mandrels are 0·048 in. in diameter. After that it is all hollow sinking, and the tube is so small that it is handled like wire. Indeed small tubes like stainless steel hypodermic needles are made in such long lengths that the tube is coiled to pull it through the die as in wire drawing. An outside diameter of 0·010 to 0·015 in., with a bore about half the o.d., is quite common. Where tubes are left in the as-drawn condition, whatever their size, their properties are those of cold worked material, so can be modified by tempering, or "blueing" as it used to be called, at some relatively low temperature such as 350° C.

Purpose of Cold Work

One may say therefore that cold drawing comes into the picture when it is necessary to produce tubes of thinner walls, or smaller diameters, or better finish, or closer tolerances, or (sometimes) longer lengths than can be made as hot finished. It is also employed to obtain certain physical properties otherwise unattainable, to make shapes other than round, to vary the diameter and thickness from

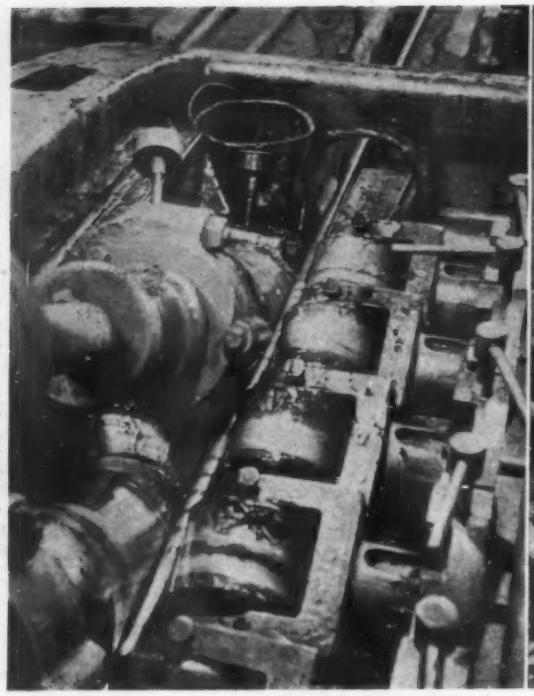


Fig. 30.—Seven-roll straightening machine.

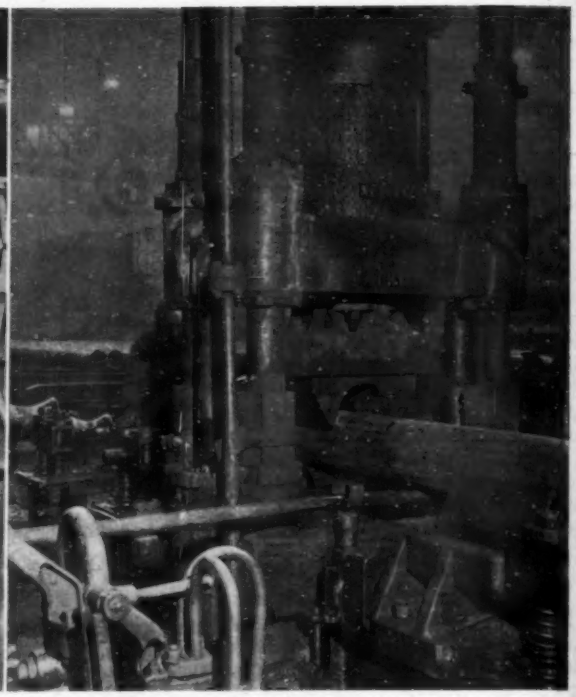


Fig. 31.—Straightening a large tube under a hydraulic press.

end to end, and to deal with small lots uneconomical to hot roll.

Modification of the circular shape is, of course, effected by using tools of appropriate contour, and the standard catalogue of a leading cold drawing company lists over a thousand different shapes, such as oval, streamline, square, and complex sections. Similarly, there is a wide variety of other cold working operations, such as tapering, putting in steps, expanding, reducing, thickening, and various other ways of modifying the circular shape or the diameter/thickness ratio, all ancillary to the making of the tube itself.

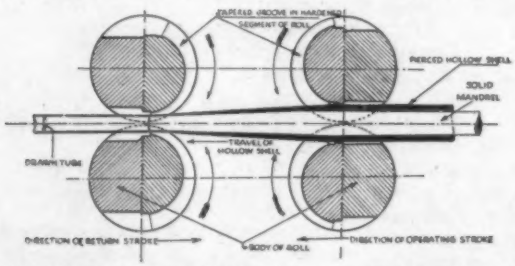


Fig. 32.—Diagram illustrating the process of cold pilgering.

EPILOGUE

It is the need for the hole in the middle (or somewhere near the middle) that makes the tube industry different from all others. It is the hole in the middle that gives the steelmaker the headache because his product has to stand what he thinks is a murderous process of turning steel inside out, which of course is not literally true. It is the hole in the middle that worries the tube-maker in billet heating, in the design and operation of peculiar oblique rolling mills, or step by step operations in rolls that seem to work the wrong way. It worries the cold drawer because it doubles the friction and therefore his lubrication problems, to say nothing of working to fine limits and gun barrel finishes. It annoys those who are concerned with pickling and lubricating, for they have to get liquid down the bore, as has he who oil quenches the finished article. Indeed it governs all our engineering, and finally involves the user in a maze of tolerances on eccentricity, mean thickness, outside diameter, inside diameter, ovality, and straightness, that have no parallel in other industries. (There are at least seven ways of assessing straightness). It is this hole, however, that confers on the tube its very shape and hence its ability to serve a bewildering variety of consuming industries not only in containing and conveying fluids of all kinds, but also structurally in combining maximum stress carrying capacity with minimum weight.

Concluded.

Steel Tube Technical Service for South America

The Tube Investments Group of engineering industries announce the registration in the Argentine of a new subsidiary company, Tubes Britanicos (Argentina) S.R., Ltd., to provide a technical advisory service for South American purchasers of British steel tubes.

This development follows the recent return from South America of the Group's Technical Trading Mission, which made an extensive study of steel tube needs and demands in the Argentine, Brazil, Chile, Peru, Uruguay and Bolivia.

The resident British director of the new company, Mr. R. D. Young, was formerly production manager of the Desford works of the Tube Investments subsidiary company, Tube Products, Ltd.

Testing of Welds in Holland

A co-operative X-ray service for carrying out tests on welded structures in which there is centralised control of radiographic technique and of interpretation of results.

USERS of welded structures and vessels welcome examination of their welds by non-destructive methods, especially X-ray apparatus, but, except for the higher class of pressure vessels, it has generally been considered to be too expensive. It is of special interest, therefore, that the shipbuilding and engineering industries of Holland have set up a co-operative organisation for carrying out X-ray examination of welded structures of all kinds, particularly for shipbuilding.

The subject was discussed by Mr. Van Ouwerkerk at a recent meeting of the Institute of Welding. Mr. Van Ouwerkerk, who is manager of the service known as the Röntgen Technische Dienst, stated that British welding technicians had made good progress in the non-destructive testing of welded pressure vessels. In Holland they had done a great deal in radiographic examination in shipyards, and had built up an organisation for training welding engineers and operators. He explained that Dutch industry utilising welding comprised shipbuilding, boiler and engine construction and foundries, and as firms desired to manufacture at the lowest possible cost, special circumstances were necessary to induce a firm to apply non-destructive testing.

The impetus for the establishment of the X-ray Technical Service, which started a year or so before the war, came from shipbuilders who had then accepted some Russian orders for all-welded boilers. The Russians specified radiographs as a proof of the quality of the weld. The order was accepted by five shipbuilding yards and the question arose, had each establishment to obtain an X-ray installation or could these be centralised? The ordering and the producing of material for construction had been centralised and there seemed no objection to adopting the same procedure for X-ray examination. In that way the Röntgen Technische Dienst was formed.

In Holland, it was stated, more time is involved in X-ray examination of shipbuilding construction than in other countries. Dutch shipbuilders have computed that in shipbuilding the X-ray examination should be divided as follows :—

Ships of 100–1,500 tons—14 days X-ray examination during the building on the berth.

Ships of 1,500–5,000 tons—3 weeks X-ray examination during the building on the berth.

Ships of 5,000–10,000 tons—1 month or 6 weeks X-ray examination during the building on the berth.

Welds tested comprised those in the hull, water-tight bulkheads, engine room foundations, welds in upper deck, in masts, foredeck and afterdeck.

It was pointed out that to measure large differences and to ascertain heterogeneities in castings the X-ray or gamma test was performed with the aid of a counting tube instead of a fluorescent screen or film. With this counting tube the emerging rays were measured. Differences appearing in the quantity of emerging rays could be read on a sensitive ammeter, from which conclusions might be drawn as to the large differences or heterogeneities in castings.

An interesting discussion followed which was admirably summarised by Mr. H. N. Pemberton of Lloyd's Register of Shipping, who said that in Holland they were dealing with a very small industrial area and that, therefore, the job of organising a central X-ray system was comparatively easy. For the industries in this country it would necessitate a number of such mobile units in the various parts of the country. He added that his experience with X-rays had been mainly confined to pressure vessels where the question of standardisation of quality of welds was not a very difficult one ; in fact it hardly arose, because the standard was high and there was no argument. But to apply X-rays to other parts of ship structures and castings they were bound to face up to the problem of acceptability, and that was where the main difficulty would arise ; it was essential, therefore, to have centralised control not only of the radiographic technique but also of the interpretation of results.

Another feature regarding Mr. Van Ouwerkerk's organisation was that the X-ray service had been set up by co-operation between firms and was not a system which had been thrust upon industry by any authority either governmental or classificational. It was an authority that the firms themselves had set up in co-operation and from that point of view it was not what might be called a profit-earning outfit.

Mr. Pemberton added that one of the questions left in his mind was the kind of action to be taken in this country. Lloyd's Register of Shipping had recently set up a brief list of what might be called industrial X-ray laboratories in this country. The underlying principle was that the X-ray laboratories should be controlled and run by the firms or industries, and that the Society, so far as its work was concerned, would require certain conditions to be complied with as regards plant, equipment, technique and personnel. Now that that system was to be applied in steel foundry work and in general engineering construction and that progress was likely in alloy steel castings for high pressure purposes, he had no doubt that X-rays for examination would play a very important part.

There was need for some centralised control in order to get unification of results, but again they would like to see this development made without having to thrust it on industry. So far as welded work was concerned no one with X-ray equipment would question the fact that, where X-ray was introduced, up went the standard of workmanship.

MR. GEORGE PATCHIN, A.R.S.M., M.I.M.M. has retired from the position of Principal of the Sir John Cass Technical Institute. His service to this Institute has extended over a period of 33 years during which it has gained a very worthy place in the scheme of technical education in this country. Dr. A. M. Ward has been appointed successor to Mr. Patchin.

Correspondence

Heat-Treatment of Low Alloy Wrought Steels

The Editor, METALLURGIA.

Dear Sir,

I have read with interest your contributor's article under the above title in the December number of METALLURGIA, but I cannot agree that he has achieved the aim of simplification referred to in the last sentence of his article. Failure to simplify is evident in three notable respects :—

(1) The symbols used to indicate ultimate tensile stress are obsolete. The suffixes from the first few letters of the alphabet appended to the En steel numbers to indicate the tensile stress were discarded when the second edition of the BS Schedule 970 was issued in 1942 and replaced by the series from N to Z as set out on page 20 of that schedule.

(2) Your contributor's Tables I and II are far less clear than the type of table adopted in BS 970, either the 1941 or 1942 editions. Table II in each instance puts concisely and clearly the relationship between chemical composition, ultimate tensile stress, and influence of mass.

(3) Your contributor is by no means always consistent in the heat-treatments given in the article.

Yours faithfully,

C. C. HODGSON.

Leyland, Lancs.
Dec. 27, 1945.

The Editor, METALLURGIA.

Dear Sir,

We have read with some sympathy your correspondent's letter in regard to our article. He writes naturally as an expert metallurgist, whereas our article was written for the practising engineer and worker not quite so intimately acquainted with the BS specifications and the fine points of technical expression as your correspondent. However, we should like to suggest that your correspondent might use the word "obsolescent," rather than "obsolete."

While it is true that "ultimate tensile stress" is now used by metallurgists, it is far from being in general use, and to many it will, for some time, be confusing to use U.T.S. instead of the still much more familiar M.S. or Maximum Stress. The clarity or otherwise of our tables depends entirely on the point of view. It is quite true that we have deliberately omitted mass effect from our tables, but the B.S. tables do not show either elongation per cent. or heat-treatment.

Rightly or wrongly, we still consider our table has advantages for the practical man, but this is not to say that we criticise the admirable British Standard specification.

Our experience is, however, that there are large numbers of your readers who are not familiar with these specifications, and who, even when they have them, find themselves somewhat confused.

As our contribution was a joint affair, it may be that there are one or two inconsistencies in the heat-treatments given in the article which have not been detected. However, your correspondent does not specify his instances, and all we need to say is that though there may be these inconsistencies, they are not inaccuracies, but represent actual practice. They must be put down to a slight lack of co-ordination of our joint opinions, and may even be regarded as advantageous, as indicating alternative treatments to the reader.

Yours faithfully,

"YOUR CONTRIBUTORS."

Sheffield.
Dec. 31, 1945.

To the Editor, METALLURGIA.

Sir,

Further to the correspondence on your article entitled "The Heat Treatment of Low Alloy Wrought Steels," your contributors have misunderstood the reference in paragraph (1) of my last letter to "symbols used to indicate ultimate tensile stress." The word "symbols" was used in the same sense as in the heading of the last paragraph of BSS. 970, 1942 (pp. 19–20), i.e., it referred to the letters which indicate the specified ultimate tensile stress.

In the schedule dated October 1942, the letters N to Z are used as symbols to indicate the minimum ultimate tensile stress. This was a change from an earlier arrangement and was made to avoid confusion. The same letters always represent the same lower limit of tensile stress range. The earlier arrangement in the 1941 schedule used the letters A to G but some confusion arose through there being two sets of letters, symbols for quite different things, and differing only according to whether they appeared in small type or as capitals. Moreover, so far as maximum stress was concerned, one letter did not always indicate the same tonnage value but varied from one specification to another. It is this obsolete series of symbols that your contributors have chosen to use. It will be seen, therefore, that my use of the word "obsolete" had nothing to do with any quibble about the terms ultimate tensile stress or maximum stress whichever one prefers to use.

Your contributors say that there are many readers who are not familiar with the BS. 970 schedule, this is probably correct, but an excellent opportunity of drawing attention to the valuable information contained in this schedule appears to have been missed.

On the matter of inconsistencies referred to in paragraph (3), whilst it would not be difficult to point these out, the process would be rather too lengthy to follow in this correspondence. A careful consideration of the information given in the text and tables will, I feel, substantiate that my observation was not entirely without foundation.

I am, Sir,

Yours faithfully,

C. C. HODGSON.

Leyland.
Jan. 3, 1946.

Allocations of Tin

THE Ministry of Supply announces that the Tin Metal Committee established by the Combined Raw Materials Board has made interim allocations of tin operative immediately to Denmark, France, Netherlands, Norway, Canada, African and Indian Ocean Territories, India, South America, UNRRA, Sweden and Switzerland. In general, tin metal tonnages concerned will be made available from United Kingdom or Belgian sources of supply and, in the case of South America, from U.S.A. also. Semis will be obtained from any of these sources.

COLD ROLLING

Recent Progress in the Design of Rolling Mills and in the Cold Rolling Practice of Steel Strip and Sheets in Great Britain

By C. E. Davies, M.I. Mech. E.

W. H. A. Robertson and Co. Ltd., Bedford

To review, even briefly, the improvements made in strip mills and auxiliary equipment in Great Britain in the past six or seven years is no easy task, but to include also progress in cold rolling practice increases the difficulty. Such a review was presented by Mr. Davies at a meeting of the "Chambre Syndicale des Lamineurs a Froid" held in Paris early last year, in which the main aspects of the subject were discussed. Although limited time prevented the discussion of full details, this review will have a special interest to British readers, and by courtesy of the author we are permitted to publish an abridged translation of his paper.

THE adoption of the four-high rolling mill is the most outstanding development in the design of steel strip rolling mills and cold rolling practice during the last seven years. It is the most efficient type for cold production of strip steel, and is the unit on which modern plants for high production strip rolling is based. In addition, however, there has been an increasing adoption of reversible mills and of continuous mills with several roll stands in tandem. The two-high mills of heavy pattern are still holding their own and are sometimes preferred for the initial passes of strip previously rolled hot; also, they are suitable for "skin" and "temper" pass rolling.

It seems improbable that the six-roll mill will come into favour again; it is less suitable for high-speed rolling, has higher initial cost and does not possess any advantage over the four-high mill. Moreover, the demand for rolling mills capable of dealing with strip of constantly increasing width has been successfully met by the design of heavy mills with larger support rolls and with bearings capable of withstanding the heaviest rolling passes at the highest practicable speeds.

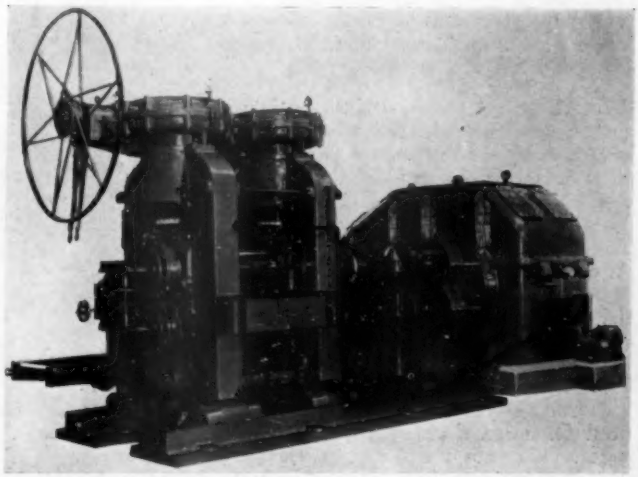


Fig. 1.—A modern two-high mill of heavy pattern with rolls of 450 mm. diameter and 600 mm. wide, with bearings of patented system of "Flood" lubrication. The combined reduction gear and pinion box is totally enclosed with universal couplings of the latest pattern between the rolls and pinions. Mills of this type generally operate at speeds from 45-90 metres per minute.

This tendency towards rolling strip of constantly increasing widths reaches its maximum in "strip-sheet" practice that is, rolling heavy coils of strip in such widths as are required for straightening and cutting off into sheets. A special case of this kind is the modern method of producing tin plate of a width varying between 600 and 750 mm., the thickness being ¼ mm., after cold-rolling and using as initial material hot-rolled strip of approximately 2 mm. thickness.

Even for strip of medium widths, that is, of 300 to 400 mm., the power and proportions of the four-high mills are appreciably greater than those of mills for similar work made during the previous period (1935–1939). At that time, strip of 400 mm. would be rolled in mills with rolls of, say, 175 mm. diameter with support rolls of 380 mm., whereas, at the present time, a rolling mill for the same work is likely to have working rolls of 200 mm. diameter and support rolls of 450–500 mm. diameter. The latter naturally involves an increase in the power of reduction and in the capacity of production. The increase in the dimensions of the support rolls indicated above allow an increase of rolling pressure of 40 to 75%.

As in the United States, four-high mills of enormous power and capacity are in operation or construction. The largest so far made by W. H. A. Robertson and Co. have rolls of 600 and 1,400 mm. diameter by 2,100 mm. width.

During the years immediately preceding the war and also during the first years of the war, the greatest expansion in rolling plant was for the production of sheets of strong aluminium alloy and comparatively few new rolling mills were built for the steel industry, which was sufficiently well-equipped to satisfy the

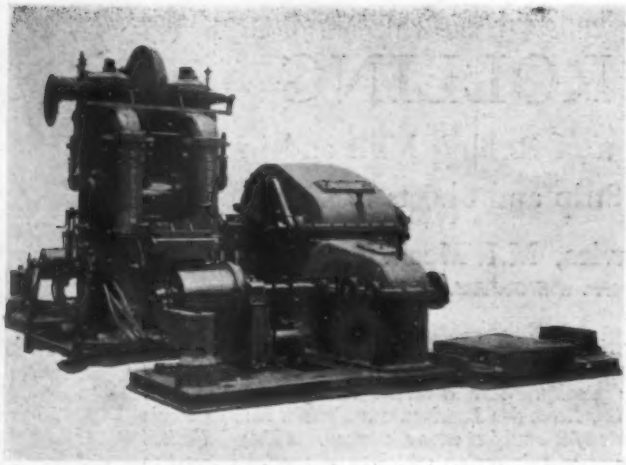


Fig. 2.—A typical reversible four-high strip mill of light pattern made in 1937/38 with rolls of 175 and 380 mm. by 400 mm. Collapsible drum coilers are provided on both sides of the mill. Many mills of this type have been supplied for variable speeds between 0-120 metres per minute.

demand for steel strip, whether mild or high-carbon steel or special alloys for the production of war equipment. It is of particular interest that W. H. A. Robertson and Co. constructed the first big four-high rolling mill installed in Great Britain, about 1937, for cold rolling stainless steel sheets up to 1,200 mm. width, and the experience gained in rolling strong light alloy sheets was obtained on these mills at that time. This led directly to the installation of similar mills for producing sheets of "Dural" quality on the immense scale required for the expansion of the R.A.F. during the war. Practically all the four-high rolling mills for this big strip and sheet production were made by my works during recent years. We were the first to design and build trains of two and three four-high mills in tandem for rolling wide strip of light alloy in heavy continuous coils for straightening and cutting into sheets to the requirements of aircraft production. In all material points of construction, power and capacity, these modern rolling mills for producing strip and sheet of light alloy are practically identical to those required for similar production in mildsteel strip.

As already pointed out, although few of these very large mills with four rolls for rolling wide steel strip are installed outside the United States, we had already constructed mills for steel strip up to 1 metre width with rolls of 300 and 750 mm. by 1,200 mm. for reversible operation, in addition to numerous small ones, both reversible and non-reversing, and also in tandem trains for strip within a range of 150 to 330 mm. width.

There is still appreciable demand for single stand four-high mills, non-reversible, more especially for limited production of narrow strip in small coils, but where the weight of the roll in comparison with its width is adequate, there is no doubt that the reversible type offers advantages by reducing the time required in handling and by maintaining the control of tension of the strip both on entering and on leaving the rolls. Where a single mill is sufficient for the desired production, the reversible mill is probably the more economical type, but for heavy coils and greater output, where two mills or more are needed, the tandem-train arrangement or continuous rolling is generally found the most economical. This applies both to mills for narrow strip and those for wide strip.

The chief advantages of tandem rolls are: minimum handling, hence reduction in the cost of labour, and the fact that each pair of rolls in a tandem train operates on a single one of the series of reductions, which permits of correct graduation in the camber of the rolls in each stand. Thus it provides the important advantage that the last pair of rolls, in the finishing stand operates on the final pass only and suffers neither fatigue nor wear caused by the initial and severest reductions which are liable to cause surface damage. This ensures the requisite good finish and precision.

Numerous small tandem trains have been constructed with three and four housings and for finishing thin strip five stands may be required.

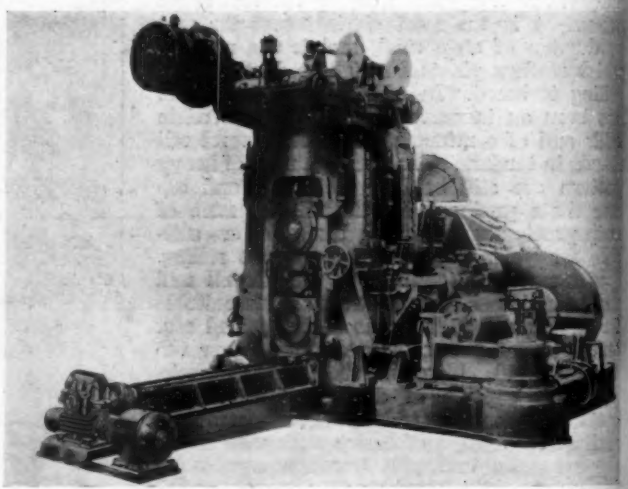


Fig. 3.—A non-reversible four-high mill of more modern construction and heavier design with rolls of 190 and 400 × 360 mm. Adjustment of the rolls is ensured by two motors which may operate either independently or together, thus affording a means for rapid adjustment of the strip thickness.

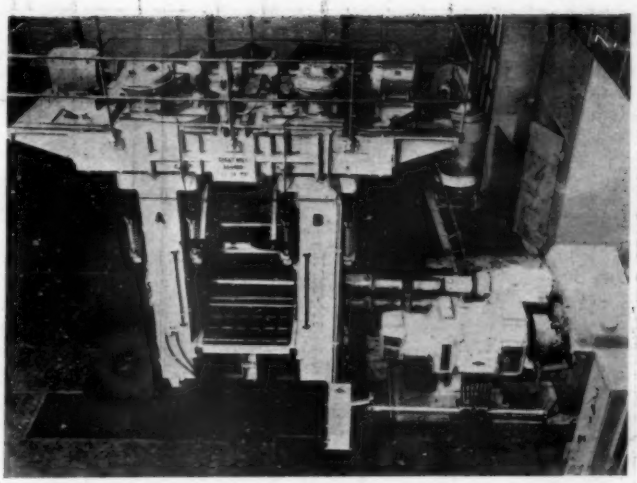
For very thin strip, say, of $\frac{1}{10}$ mm., even in coils of moderate weight, the tandem mill shows great efficiency in production. Some users prefer that the first stand which takes the hot-rolled strip should be a two-high mill, as being better able to deal with the gauge variation and the rougher surface of the acid cleaned hot-rolled strip.

With regard to the cost of the plant, the tandem mill is economical where two stands or more are required for the output. A tandem mill with two or three housings is cheaper than an equal number of reversible or independent mills, since the former only calls for a single coiler, and as the electrical equipment is less expensive.

Another remarkable feature in all modern plant for steel strip is that, instead of a large number of small units of low power, a minimum number of powerful high-capacity mills is installed with the resulting saving in labour per ton produced.

It is with regard to the rolling speeds that considerable progress has been made during these latter years. Before 1939, the maximum rolling speeds generally adopted in England and in Europe would rarely exceed 150 metres a minute. At present, this is about the lowest working speed of a modern mill and, excepting the cases where the coils are short, the maximum speeds usually vary between 200 and 350 metres. In the case of modern mills for wide strip dealing with coils of 3,000 to 7,000 kilos in weight, 450 metres and even 900 metres have become normal practice.

While I myself have, for many years consistently favoured greater rolling speeds since the time when the common rolling speeds for strip were about



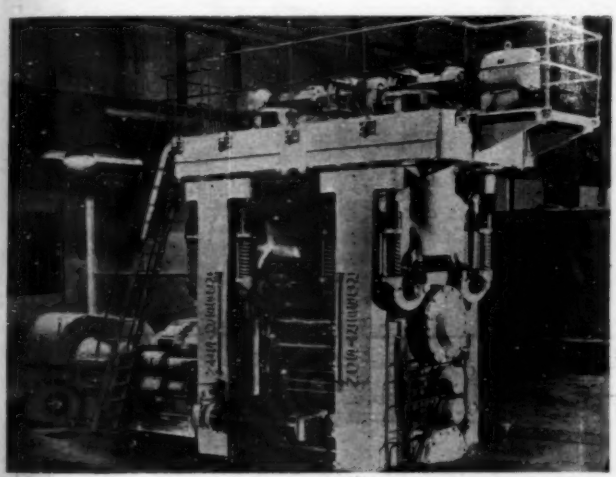


Fig. 4.—One of the several four-high mills installed for cold rolling of stainless steel sheet 1,200 mm. width, seen from the outlet end. The rolls are 350 mm. and 940 mm. in diameter by 1,500 mm. wide.

30 metres a minute, I would make clear that the greatest practicable speed is not necessarily the most economic one. The rolling speeds should be chosen to meet individual conditions, the chief of which is the length of the coil available or the weight of the coil for a certain width of strip. This determines the proportion of the actual rolling time compared with the total time of operation, including losses of time in handling the coils, etc.

Generally speaking, the most efficient rolling speed increases with the weight of the coil and also with a given coil weight as the thickness decreases. With speeds higher than approximately 50 metres it is necessary to provide a variable speed so that the speed for each pass may be adjusted to the most economic rate, and it is customary to allow for rolling at speeds between the maximum and 50% of the maximum, with means for starting at slow speeds for entering the strip and adjustments, from zero up to medium speed, a characteristic speed range being 0–150–300 metres per minute, or similar.

Fig. 5.—The same mill as in Fig. 4 but from above and from the inlet side. Adjustment, necessarily very exact when dealing with thin sheets, is ensured by two powerful motors. These mills do not as a rule operate at speeds in excess of 30 metres per minute for this hard steel quality.

With a tandem train, the higher speeds are more economic than those recommended for single-stand mills, reversible or not, and in continuous tandem rolling, the effective output is practically proportional to the finishing speed of the rolls in the last stand. Since it is the mean rolling speed that counts, the maximum speed provided for should be high enough to allow a margin above the probable maximum working speed.

The fact that high speeds signify motive power increased in proportion and more expensive electric equipment shows the need for thorough examination of each programme before specifying the range of speed for any rolling mill.

Parallel with the progress in the design of rolling mills, the study of the theories relating to the art of rolling has been duly pursued and our practice is to base all designs for rolling plant on calculations of rolling pressures and power required.

These investigations have shown the importance of uniform and adequate tension of the strip on entering the rolls and on being coiled. For medium speeds and coil weights, adjustable friction clutches and brakes for controlling the tension are still employed and have the merit of low plant cost and simplicity. With higher speeds and heavy coils, the coilers are driven by separate motors synchronised with the main mill motor by a system of automatic control so as to maintain a preset, uniform tension while the strip is coiled. On the input side of the rolls, the strip may be paid out by the drum connected to an electric braking generator, the power and speed of which are similarly automatically controlled, thus applying the necessary back-pull and returning a proportion of the power to the mains. These systems of electric control, referred to as "Metadyne," "Amplidyne," "Magnavolt," etc., differ in details, though answering the same purpose. Such electric plants represent a high proportion of the total cost of a modern strip rolling plant.

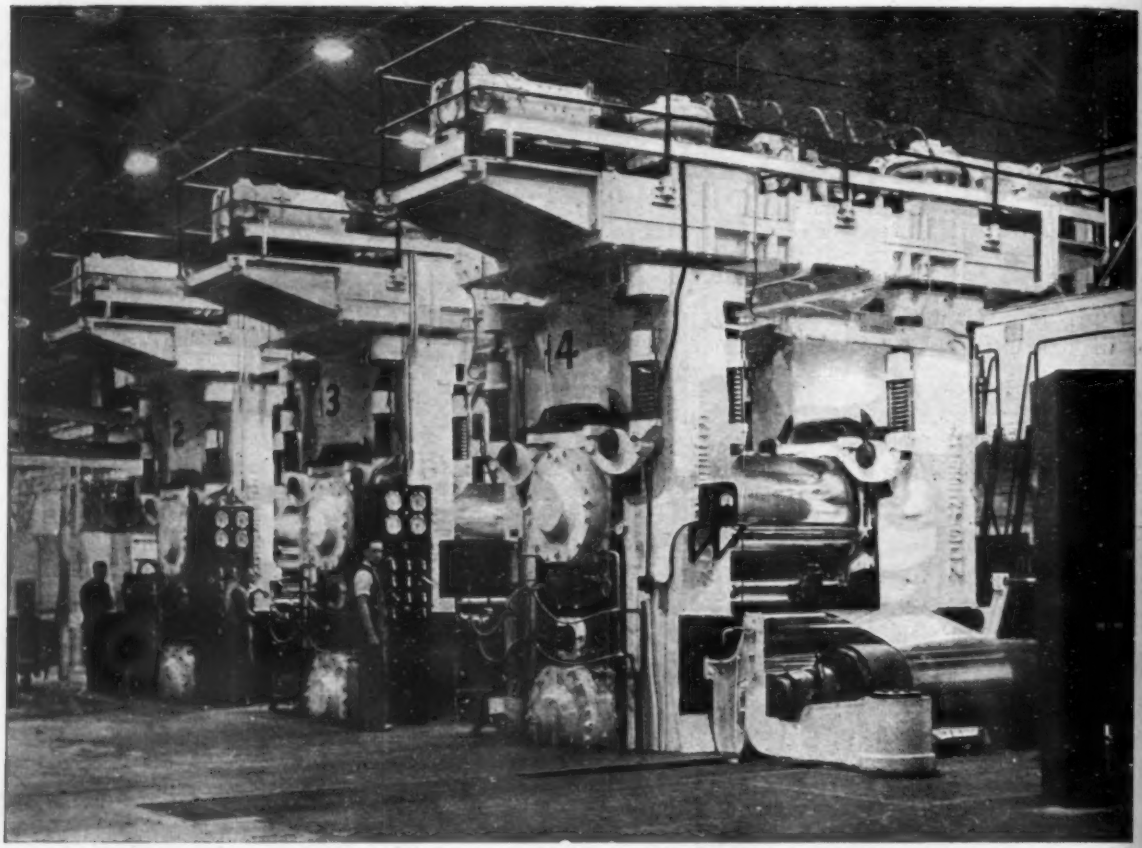


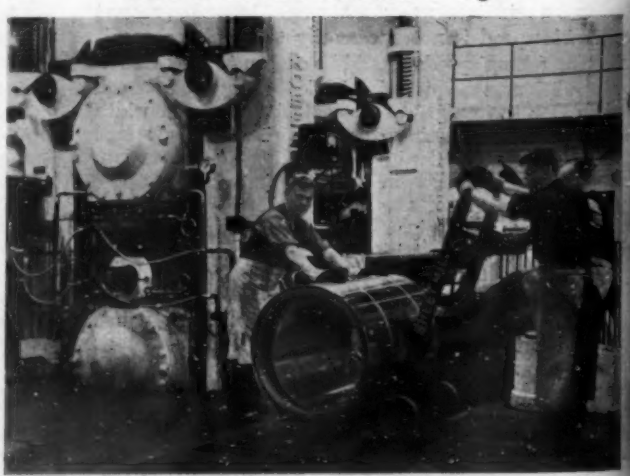
Fig. 6.—Showing a continuous rolling mill in tandem for strip. The mill with three stands is seen from the output side and is fitted with rolls of 380 mm. and 940 × 1,800 mm., each housing, and also the coiler, being driven by individual motors, all of which synchronised to give finishing speed up to 120 metres per minute. The plant is capable of finishing heavy coils of strip up to 1,300 mm. wide in thickness from $\frac{1}{10}$ mm. to $\frac{1}{10}$ mm. in light alloys.

The tandem mill for strip may call for the provision of tension control between the housings, but the tendency is to eliminate all automatic control of the rolls speed in the successive mills. We generally provide an equipment for applying a known and controlled tension with indicator to guide the operator in settling the relative speeds of the rolls.

From a mechanical view-point, modern strip mills, whether two- or four-high, can be guaranteed to operate satisfactorily at any speed desired.

The question of temperature control for the rolls is of great importance. The old system of internal cooling of the rolls is practically useless and some form of external cooling such as by jets of soluble oil solution must be adopted. A high temperature of the rolls is not harmful *per se*, but it is essential to maintain a *uniform* temperature in order to prevent any change in the shape of the rolls, or their camber, and also any change in thickness, due to variation of temperature, in the course of rolling a coil. My works have designed and supply a cooling system which comprises jackets which partly encompass the working rolls and through which the cooling liquid circulates, with a means for controlling the quantity of coolant along the roll width. This system offers the advantage of being cleaner than the jet system and at the same time it permits of separate application of a lubricating oil on the strip or on the

Fig. 7.—Showing the finished coil removed from the coiler of the mill illustrated in Fig. 6.



rolls, this lubrication being preferably ensured by a system of atomising jets. Experience and theory have shown the importance of reducing friction between the rolls and the metal.

The reductions per pass in a modern strip mill are considerable, notwithstanding the high rolling speeds and the heat engendered and transferred to the rolls, in excess of the amount which can be radiated by the latter, requires to be dissipated by an effective system of cooling.

In order to ensure precision and uniformity of thickness within the narrow limits specified at the present time, the general custom is to mount automatic gauging devices, giving a continuous reading of the variations in thickness within limits of about 2·5/1000 of a millimetre. Obviously, with such devices, it is necessary to provide means for adjusting the rolls very quickly to make any necessary corrections in thickness. Even the smallest of high-speed strip mills is fitted with powerful electric control of the rolls in order to make a rapid adjustment. For this purpose a two-motor drive is required with suitable push-button control, each screw being connected up to one of the motors, both being maintained in synchronism by means of a magnetic clutch when both screws are operated simultaneously. In order to indicate the setting of the rolls, an electric "Selsyn" system is frequently preferred to indicators with mechanical control. Due to this device, the slightest adjustment of the rolls is instantly indicated with precision on a dial or by indicator of the revolution counter type located on the control panel.

In harmony with the cold rolling practice of wide strip in heavy coils, consideration must be given to the question of supplying the hot-rolled material. Cold rolling of wide strip would have been adopted earlier in England had it been possible to obtain wide hot-rolled strip in coils of economic weight. It will be easily understood that the installation of a train of continuous hot mills with roughing and finishing rolls involves an extremely heavy capital expenditure and owing to the rate of production of such a plant a very great output of some 10,000 to 14,000 tons per week of 140 hours has to be envisaged to ensure economic production. My works include hot rolling mills in their range of production and are examining particularly plant suitable for a smaller output. We have developed combined reversible and continuous systems which can be installed at lower cost than the fully continuous hot strip mill.

By increasing the capacity of production by using wide strip rolled in heavy coils there has necessarily been great progress in the auxiliary equipment such as continuous pickling plants, shears for trimming the edges and slitting, and also machines for flattening and automatic cutting to length. With regard to this latter machine, the Hallden type, which we have been

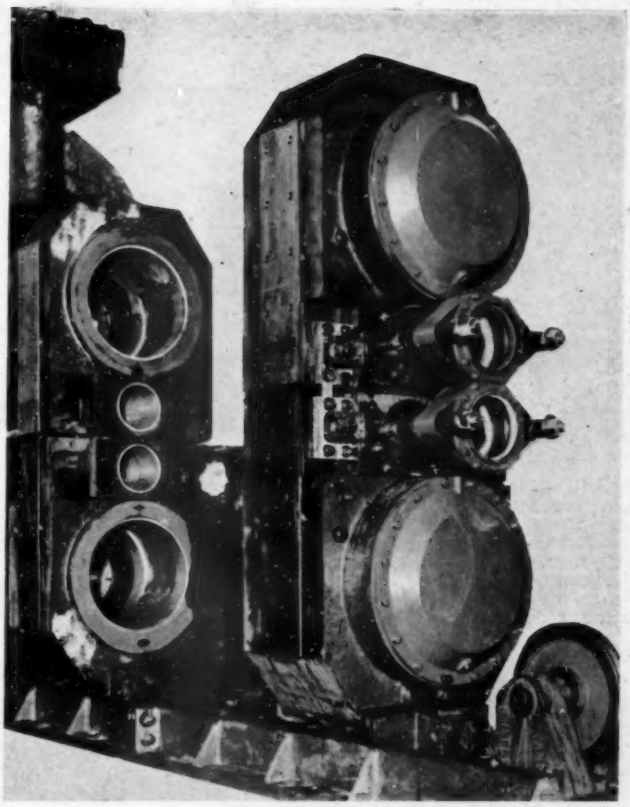
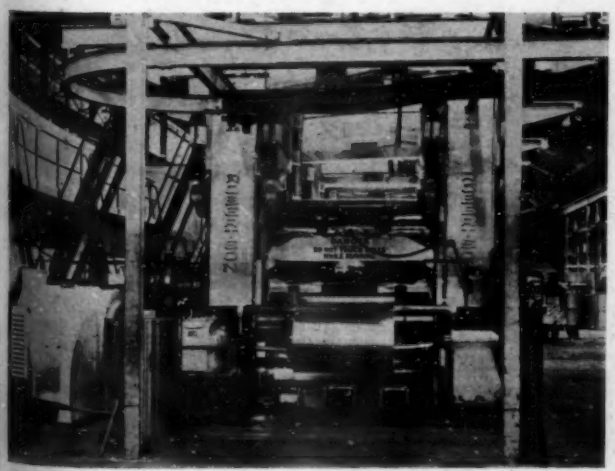


Fig. 9.—View of details of chocks and bearings for "Flood" lubrication withdrawn from the mill by means of a crane cable (rolls are not fitted). The spring mounted thrust bearings obviate excessive axial thrust, due to faulty alignment of the rolls, and give instantaneous indication of any axial thrust on the working rolls due to incorrect alignment. In this four-high mill the rolls are of 500 and 1,250 mm. diameter by 2,100 mm. wide, making up a two-housing tandem train for strip up to 1,800 mm. width.

Fig. 8.—View of inlet end of continuous mill showing the strip being paid out and introduced between the rolls by means of the flattening and decoiling machine driven by motor. A "Bridle" with staggered idle rollers, above and below the strip operated by a compressed air cylinder and shown with the upper part in raised position, is provided to maintain the strip flat up to the point of insertion between the rolls while at the same time applying some back tension.



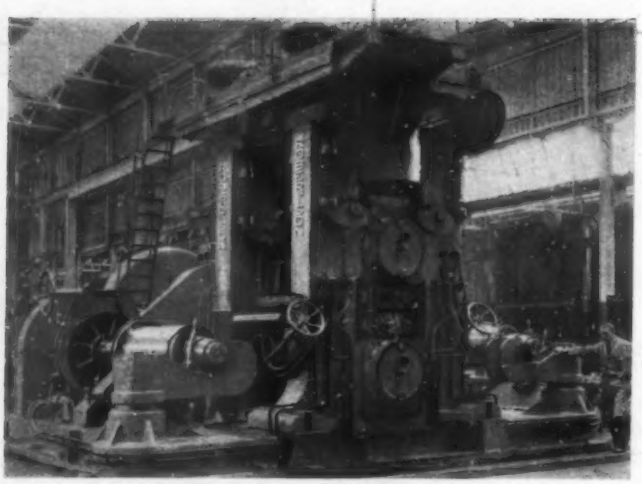


Fig. 10.—A typical reversible four-high mill of heavy pattern for strip, the design of the housings being similar to those already shown. The rolls are of 300 and 750 mm. diameter, with a table of 1,200 mm. The mill is designed to roll steel strip of 1 metre width, reducing from a thickness of 3 mm. down to $\frac{3}{10}$ mm. without intermediate annealing, at variable speed up to 150 metres per minute.

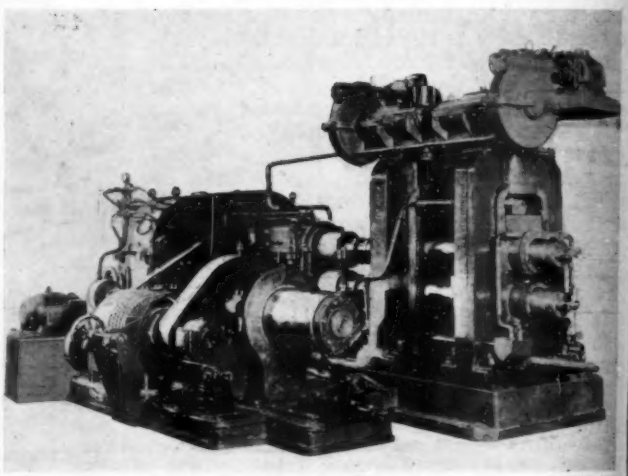
making for several years, is about to be replaced by the newer Hallden machine with flying shears, where the output warrants the expense. This machine flattens the strip and cuts off to exact lengths at speeds up to 90 metres per minute. Several of these have been installed in the course of the last five years.

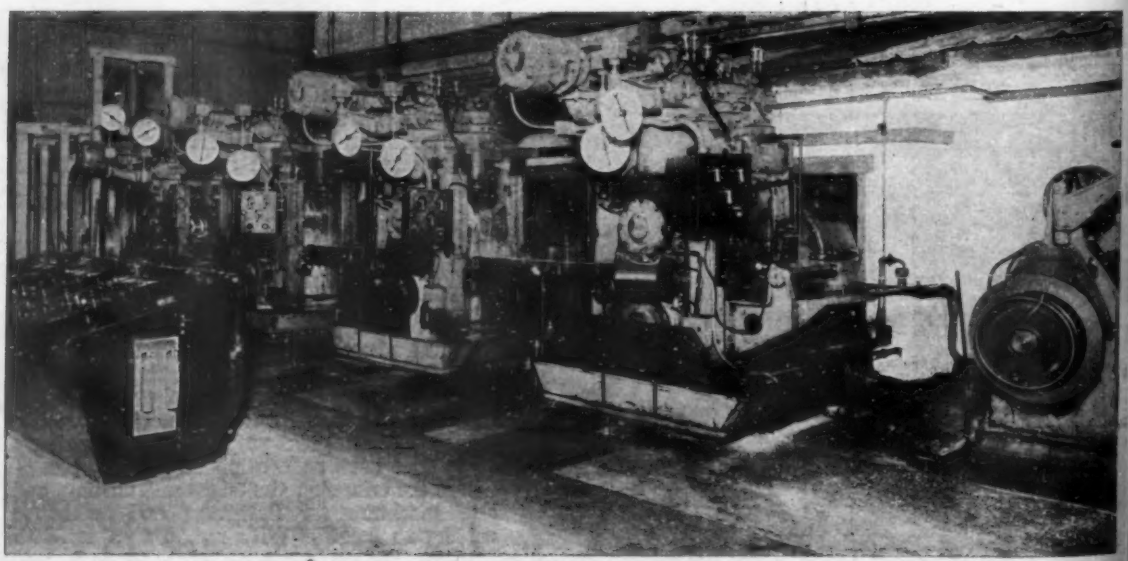
Fig. 11.—A tandem four-stand mill installed last year for cold rolling all qualities of strip steel. Generally speaking, it represents the most modern pattern of continuous tandem mill for narrow strip steel which has given very good results by finishing all thicknesses down to $\frac{1}{10}$ mm.

As an auxiliary to the cold reducing mill, it is usual to install mills for a light finishing pass or "skin" pass after annealing. These machines may be two-high for narrow strip and four-high for wide strip, and they operate at high speeds while affecting a comparatively slight reduction in thickness of the previously rolled strip. The power required for driving such mills is generally small compared with the proportions of the mill, but a high controlled tension on the strip is usually provided.

Acid cleaning plants operating on a jet principle and giving more rapid and uniform results with a saving in acid consumption have

Fig. 12.—A two-high mill for the "skin pass," that is, the light pass generally applied to annealed strip previously cold-rolled in continuous or reversible rolls. The rolls are of 350 mm. diameter by 600 mm. width for strip up to 510 mm. wide and down to $\frac{25}{100}$ mm. thickness.





been examined and are gaining favour. It has been impossible in the limited space to deal adequately with the subject or to discuss in full detail all the improvements made to strip mills and auxiliary equipment during these last five years, but some idea has been given of the progress achieved in Great Britain in the construction of mills and in rolling practice.

We are especially indebted to Messrs. W. H. A. Robertson and Co. Ltd. for permission to illustrate some of the special strip mills designed, constructed and installed by them during the period under review, these illustrations are selected from the many which were shown on a screen during the course of the lecture in Paris.—EDITOR.

Captain L. Warner, A.F.R.Ae.S.

CAPTAIN L. W. WARNER, the Deputy Director General of Aircraft Production, has retired from the Civil Service. He has been directly associated with aircraft construction since the earliest developments and, in consequence, his career has been of more than ordinary interest, as this brief outline indicates.

After qualifying as a mechanical engineer, "Plum" Warner, as he was familiarly known, joined the staff of Short Bros., at Leysdown, where he acted as experimental engineer to Mr. Horace Short on aero engines, transmission gear, and installations. From 1909 to 1914 his work at Leysdown was associated in the early problems of flying and aeronautical engineering with Sir Frank McLean, Lord Brabazon, Hon. C. S. Rolls, Mr. Cecil Grace and Mr. Ogilvie.

In June, 1914, Mr. Warner joined the Aeronautical Inspection Department, which was then a unit of the Department of Military Aeronautics and on the outbreak of war in that year he was concerned in setting up aerodromes to receive, assemble and flight test aircraft coming from production factories. Subsequently, he became successively Assistant and Chief Inspector on aero engine, instruments, radio equipment and armament and was finally responsible under Colonel Outram for the technical direction and inspection of complete aircraft manufactured and assembled at airframe firms throughout the country. In 1938 he left the A.I.D. to become Air Ministry Assistant Director responsible for the production of all bomber types. From 1939 to his retirement he was successively Deputy Director, Director, and finally Deputy Director General of Aircraft Production at the Ministry of Aircraft Production.

Mr. Edgar Pam

WE regret to record the death, on December 20, of Mr. Edgar Pam, a Director of The Mond Nickel Company Limited, and President of the Institution of Mining and Metallurgy.

A mining engineer by profession, Mr. Pam received his early training at the Royal School of Mines and was engaged for many years with the Central Mining and Investment Corporation, Limited, in South Africa, with whom he had a distinguished career and eventually became General Manager of the Modderfontein East, Limited.

During the war of 1914–18, Mr. Pam saw service in the Royal Engineers in France, where his mining experience was of considerable value in the military tunnelling operations. He retired from the Army with the rank of Lieutenant-Colonel and was awarded the Order of the British Empire, Military Division.

Mr. Pam joined The Mond Nickel Company in 1928 as Consulting Mining Engineer and, after the merger with the International Nickel Company, he was appointed assistant to the Delegate Director and subsequently Deputy Delegate Director. In the Spring of 1945, he became a member of the Mond Board. He was closely concerned with the Company's operations in Northern Finland down to the time of the outbreak of war there.

Mr. Pam had been in poor health for some time. His many friends and colleagues on the Company's staff join in deepest sympathy with Mrs. Pam.

British Cast Iron Research Association New President

DR. HAROLD HARTLEY, who is the Technical Director and Managing Director of Radiation Limited, was elected President of the British Cast Iron Research Association at the recent annual meeting. He is one of the leading authorities in connection with the domestic utilisation of town gas. Entering Manchester University in 1904, he studied under Professors Dixon, Perkin and Bone during a period of great research activity in the Manchester School. He graduated in 1907 with First-Class Honours at the head of his year and was elected to a Gartside Scholarship in Industry and Commerce. After a year's work in the School of Economics, he travelled in Norway and Canada, collating data on the cost of power production for electro-chemical industries. While in Canada, Dr. Hartley carried out research work at McGill University. On returning to this country in 1909 he was elected to the Gas Research Fellowship at Leeds University on the recommendation of the late Professor W. A. Bone, the first Livesey Professor. This started a close friendship which was terminated only on the death of Professor Bone in 1938.

In 1912, Dr. Hartley was appointed to the staff of the Richmond Gas Stove Co. at Warrington to build up a research section. It was whilst at Warrington that he was especially concerned in the development of furnaces both for non-ferrous metal melting and for heat-treatment processes generally. In 1919, he took the D.Sc. degree at Manchester, one of the theses submitted being concerned with the study of the melting of the brasses.

With the formation of the Radiation Group in 1919, Dr. Hartley was appointed Chief Chemist and head of the Research Department. He moved to London in 1922 when Radiation House was opened in Grosvenor Place. In 1925 the new Central Research Laboratories were inaugurated by the late Sir David Milne-Watson and there followed a period of activity which has led to marked developments in gas and coke burning apparatus. In 1937, additional new and enlarged laboratories were opened in Birmingham, and in September 1939, the Central Research Organisation was transferred to the Midlands. It was in October 1939, that Dr. Hartley was appointed to the Board of Radiation Limited as Technical Director. He became a joint Managing Director in 1944.

Dr. Hartley has been for many years an active member of the British Cast Iron Research Association. He was elected to the Council in 1934, became Chairman of the Research Committee in 1936 and Chairman of the Council in 1938, which office he vacated on the occasion of his election to the Presidency.

Symposium on Production and Design Limitations and Possibilities for Powder Metallurgy Parts

Many types of small parts are now being made by powder metallurgy technique, and tolerances can be held as close as 0·001 in. Various combinations of metals, non- metals, and non-miscible metals are possible. Among the parts now being made from powder are gears, bearings, screens, filters, contact points, copper carbon brushes, radio parts, and various brass, steel and aluminium parts. This review deals more particularly with design factors in powder metallurgy.

POWDER metallurgy has made considerable progress in recent years as a means of manufacturing finished and semi-finished products. The method of compressing metallic powders in dies and subsequently heating them to obtain desired shapes offers raw material savings, the elimination of scrap or excess metal, savings of machine tool and labour costs and certain definite inherent advantages in the composition of the finished product. Various aspects on the subject of design were presented at the first conference of the Powder Metallurgy Committee of the American Institute of Mining and Metallurgical Engineers. They comprised a symposium of twelve papers, with a foreword by Mr. F. N. Rhines, outlining the objects and aims of the Committee.

In the first paper design factors for metal forms with which powder metallurgy may compete are briefly reviewed by F. W. Peters. These factors include sand casting, die casting,, permanent-mould casting, precision casting, machined bar stock, cold-heading drop-forging, and stamping and drawing. The advantages and limitations of each process are discussed and consideration is given to the competitive field for powder metallurgy.

Powder metallurgy, as applied to machine parts, both ferrous and non-ferrous, including gears, ratchets, levers, sliding blocks, cams, etc., are considered by J. Langhammer. Generally speaking, the parts that are adapted to powder metallurgy are of shapes that can be cast easily by simple foundry methods and without cores, except for a plain core that would form the bore. The advantages of powder metallurgy for such parts are briefly dealt with and limitations both general and specific, such as sharp corners at points of intersection, large fillets and undercuts, referred to.

The methods of manufacturing, the design possibilities and the properties of pole pieces for direct-current electric motors and generators made from iron powder are discussed by F. V. Lenel. Curves of magnetisation and permeability of magnetic material made from iron-powder and of electrical sheet steel, are given and show the necessity of extra turns being put in to a field coil to compensate for the lower permeability at flux density, when a steel pole is replaced by an iron-powder pole piece. It is also shown that the magnetic properties of pole pieces are influenced by the choice of raw materials, Table I, the density to which they are briquetted and the heat-treatment which they receive.

In the fourth paper of the series, dealing with bearings from metal powders, W. R. Toeplitz states that porosity has a decided effect on the manufacturing techniques, the structure and physical properties, the oil content and on the installation and service of oil-retaining bronze bearings. The normal range of oil content for porous bronze bearings containing 89% copper, 9·75% tin, 1·25% graphite, is from 35 to 16%, which is in the specific gravity range of 5·8 to 7·3, and as the oil content decreases the physical properties improve. Not only is the size of the pores important, but so also is the type of porosity, which must be intercommunicating. Porosity is also a most important factor in the manufacturing of bearings from metal powders, as the amount of porosity has a great effect on size changes of the compacts during sintering, and porous structures enable the gases of the furnace atmosphere to penetrate through the compact and reduce oxide films, etc. The presence of porosity permits sizing to extremely close tolerances.

Two papers deal with electrical parts manufactured from metal powders. In the first, brushes and allied parts made from two types of metal-graphite are considered by R. R. Hoffman. In one type, the metallic powders are held together by means of a bonding agent such as pitch or tar, and generally contain the lower percentages of metallic powders, the bonding material

TABLE I.—MAGNETIC PROPERTIES OF RING SAMPLES BRIQUETTED AT 60,000 LBS. PER SQ. IN., SINTERED 3 HOURS AT 1315° C. IN HYDROGEN.

Source of Iron Powder.	Residual Shrinkage of Samples in Sintering In. per In.	Density of Sintered Sample Grams per C.C.	Maximum Permeability	Magnetising Force Oersteds for Flux Density of 10,000 Gauss.	Flux Density Gauss for Magnetising Force of 40 Oersteds	Residual Induction Gauss from 10,000 Gauss.	Coercive Force Oersteds from 10,000 Gauss.
Electrolytic	0·008	6·82	3100	3·9	12,700	9,300	1·6
Decarburised Comminuted Steel Shot	0·012	6·63	2150	14	11,000	9,000	2·0
Hydrogen Reduced Mill Scale	0·018	6·20	1340	30	10,300	8,300	3·1
Hydrogen Reduced Oxide from Steel Scrap	0·023	6·01	1380	40	10,000	8,300	2·9

being required because there is not sufficient continuity of metal to provide the required strength by sintering or alloying. The other type, containing the higher percentage of metal, requires no bonding agent, the actual sintering of the metal particles giving sufficient strength. The physical properties of the metal-graphite materials are discussed, consideration is given to the design of the brushes and parts and to the tolerances required, and manufacturing advantages are briefly reviewed. In the second paper, dealing with electrical contacts, E. I. Larsen emphasises the absolute necessity of rigid control of raw materials and fabricating processes. The necessity of close collaboration between contact users and contact fabricators, so that correct contact combinations are obtained, is also stressed.

C. R. Fulton deals with the making of permanent magnets by sintering, using iron-nickel-aluminium alloys (Alnico). After considering the sintering process, design, size limitations and physical properties, it is concluded that close tolerances, thin sections, designs that require sharp feather edges on the punches and small holes, undercuts or holes not parallel to the axis of pressing, blind holes or counterbores and tapers in the direction of pressing, and magnets too long in the direction of pressing in proportion to the area of cross section should be avoided in order to secure the most satisfactory product for the minimum cost. Uniform thickness in the direction of pressing should also be maintained.

Friction articles of rather large pressing area in distinction to other metal powder articles such as bearings, electrical contacts and magnets, are discussed in a brief note by C. T. Cox, who considers the selection of the mixture, the necessity for obtaining adequate strength, the limitations and the field of usefulness of such parts.

F. R. Hensel and E. I. Larsen describe a number of experiments of an exploratory nature, with fine silver, coin silver, silver-cadmium oxide, and silver-nickel copper compacts, prepared by powder metallurgical methods. Pressing at temperatures ranging from 25° to 450° C. was found to have little effect on the density and hardness of fine silver compacts. The density of fine silver compacts pressed at 12·5, 25 and 50 tons per sq. in. and sintered at 880° C. in air was the highest on compacts pressed at 12·5 tons per sq. in. and the higher density was retained throughout subsequent repressing and resintering operations. Silver compacts sintered in air have higher physical and electrical properties than those sintered in hydrogen, and those sintered in hydrogen show mechanical and electrical properties similar to those of wrought alloys. Such compacts respond to precipitation-hardening treatments to a high degree, but increasing additions of nickel (5 to 50%) to sterling silver compacts progressively decrease their susceptibility to precipitation-hardening, Table II. Replacing cadmium with cadmium oxide in silver compacts, materials of high electrical conductivity are obtained which have applications as electrical contacts.

Experiments carried out on sintered and hot-pressed copper-tin powder compacts are described by C. G. Goetzel. Powder mixtures corresponding to 95–5 90–10, 85–15 and 80–20 copper-tin, were sintered at 800° C. for 1 hour in hydrogen, and hot-pressed up to 600° C., and density, weight-volume measurements, hardness, compressive strength and micro tests made on the cylindrical compacts. It was found that all the sintered bronze compacts underwent only negligible changes in weight during treatment, but that volumetric changes were considerable. Density, hardness and compressive strength increased with rising mould pressure, but for sintered and hot-pressed materials. Specimens hot-pressed at 300° C. and 500° C. showed the lowest and highest physical properties respectively with sintered alloys having intermediate values for density and compressive strength, but the lowest values for hardness. Micro-examination showed that pre-alloying of the powders promoted increased homogenization in all hot-pressed samples, but was much less effective in sintered specimens with virtually no effects in the 95–5 and 90–10 compositions.

An abstract of a metallographic study is given by C. J. Bier and J. F. O'Keefe of the sintering process in copper powder as shown by the structural changes that occur as a pressed powder bar is sintered. The bars were given treatments that covered the furnace temperature range from 840° to 1050° C., the time period from 2 to 60 minutes, and a series of briquetting pressures from 20,000 to 100,000 lb. per sq. in.

In the last paper of the series, experiments on the effect of pressure on metal-powder compacts are dealt with by J. F. Kuzmick. Density, hardness, tensile strength and elongation, were determined and the micro-structure studied on sintered specimens of tin, copper, 70–30 brass, electrolytic iron and aluminium

TABLE II.—DATA ON SILVER COMPACTS CONTAINING VARIOUS AMOUNTS OF NICKEL.

No.	Composition.		Pressure	Pressed Density	Sintered Density	Repressed Density	Hardness after Repressing	Density as Quenched	Hardness as Quenched	Hardness as Aged
	Sterling Silver	Nickel	Tons per sq. in.	Gm. per C.C.	Gm. per C.C.	Gm. per C.C.	Rockwell F.	Gm. per C.C.	Rockwell LST	Rockwell F.
1	95	5	10	7·6	6·02	9·74	84–86	8·44	22–30	35–42
			20	8·45	7·02	9·76	83–85	8·92	34–37	45–50
2	90	10	10	7·56	6·54	9·72	85–86	8·48	32–35	24–28
			20	8·35	7·11	9·72	84–85	8·74	35–39	31–32
3	85	15	10	7·51	6·28	9·55	85–86	8·38	31–41	20–23
			20	8·23	6·82	9·59	84–86	8·52	33–38	20–24
4	80	20	10	7·26	6·06	9·47	86–87	8·28	31–38	19–24
			20	8·04	6·69	9·47	85–86	8·42	31–38	22–30
5	75	25	10	7·09	6·03	9·37	86–88	8·24	34–40	28–30
			20	7·88	6·70	9·42	86–87	8·52	41–44	37–39
6	70	30	10	6·98	5·95	9·26	87–88	8·26	40–46	33–37
			20	7·76	6·60	9·22	86–88	8·48	45–49	42–43

powders. From these experiments it was concluded that for relatively short-time sintering, moulding pressure is a very important factor in the final physical properties of the sintered specimens. The effect of pressure is different for each metal, and no general rules can be drawn that would apply to all metals. In many cases, for a particular metal powder and sintering temperature, there is a critical pressure at which the best physical properties can be obtained. The principle of cold work and annealing and their effect on grain structure applied to metals, holds true for sintered metals; and particular size, at least for electrolytic powder, does not have a great effect on ultimate grain size.

Some Recent Appointments

Mr. G. W. Lacey, C.B.E., B.Sc., A.R.I.C., General Sales Manager responsible for the Sales Division of the British Aluminium Co. Ltd. has been appointed a member of the Board of Directors of the Company.

Mr. E. A. Langham, who has recently returned from India, has taken up his appointment as Sales Manager in the Sales Division, from January 1, 1946, as previously announced.

On the appointment of Mr. E. A. Langham as Sales Manager, Mr. A. W. Langham, who has been Acting Sales Manager and responsible for the Sales and Sales Planning Departments, has now taken up his appointment as Sales Planning Manager, as previously announced.

Mr. C. L. Railton, A.M.I.E.E., A.M.Inst.W., of the Ministry of Supply Advisory Service on Welding, has been released to take up an appointment with the Research Department of the Tube Investments Group of engineering industries.

Previously on the welding staff of the Metropolitan Vickers Electrical Co. Ltd., Manchester, Mr. Railton has for the past five years been associated with the Armaments Design Department as adviser on welding.

Mr. T. W. Edwards, commercial manager and secretary of Park Gate Iron & Steel Co., Ltd., has been appointed assistant managing director. Mr. H. Williams has been made a director and general manager of the Company.

Dr. D. S. Anderson, for the past fifteen years principal of the Central Technical College, Birmingham, has been appointed director of the Royal Technical College, Glasgow.

Dr. A. Harvey, principal of Scunthorpe Technical High School, has been appointed principal of the City of Cardiff Technical College.

Mr. E. Moreton Palin, B.A., A.M.I.Mech.E., has been appointed export manager of Edgar Allen & Co., Ltd.

Mr. A. F. C. Gardner, for thirteen years technical representative with Newton, Chambers & Co., Ltd., has been appointed northern area manager for Gibbons Bros., Ltd., of Dudley.

Mr. D. W. Cooper, who, in February, 1942, was seconded from George Cohen, Sons & Co., Ltd., to take up the appointment of assistant controller of machine tools at the Machine Tool Control, and has for the last year been director of machine tool disposals, has joined the board of the Selson Machine Tool, Co., Ltd. Selson's are one of the group of companies, of which George Cohen Sons, & Co., Ltd., are the parent concern.

Lieutenant-Commander F. G. Williams, R.N.R., late of British and Continental Traders, Ltd., London, has been demobilised after 4½ years Naval Service, and has now joined the Sales Staff of Messrs. Bradley & Foster, Ltd., Darlaston Iron Works, Darlaston, Staffs.

Mr. Mark M. Cansick, formerly Commercial Manager and Publicity Manager of Specialloid Limited, has been appointed Secretary of that Company. He will continue to handle the Publicity affairs of the Company.

Dr. H. M. Glass has been appointed Director of Research with General Refractories Ltd., of Sheffield. Formerly of I.C.I. Ltd., of Billingham, Dr. Glass is a native of Gateshead-on-Tyne. He graduated in 1931 with an honours degree in chemistry and his efforts in physical chemistry research earned him the distinction of being Pemberton Research Fellow two years later. He further graduated M.Sc. in 1933 and Ph.D. in 1935.

During his first eight years with I.C.I. Ltd., Billingham Division, he was engaged in the research and plant control of fertiliser production. During more recent years full responsibility of the Non-Metallic Materials Section of the Billingham Division was borne by him and entailed research in, advice on, and the reaction of such non-metallic materials as refractories, chemical stoneware, chemically resistant cements and concretes, vitreous enamelled ware, plastics and rubbers, etc., used in the construction of chemical plant.

Forthcoming Meetings

Institution of Engineers and Shipbuilders in Scotland.

Jan. 29. "Modern Machine Tool Practice," by T. P. N. Burness.

Feb. 12. "Individual and District Heating," by D. V. H. Smith.

Institution of Mechanical Engineers. Scottish Branch.

Jan. 31. "Jet Propulsion," by Air Commodore F. Whittle, C.B.E.

Feb. 7. Thomas Lowe Gray Lecture, by G. O. Watson.

Institute of Metals (Scottish Section).

Feb. 11. "Precious Metals" by J. C. Chaston, B.Sc. Ph.D.

Staffordshire Iron and Steel Institute.

Feb. 11. "Gas Turbines and Jet Propulsion," by Dr. S. G. Hooker.

North East Coast Institution of Engineers and Shipbuilders.

Feb. 8. "Some Aspects of Gas Turbine Development for Aircraft Propulsion," by Dr. S. G. Hooker

Institute of British Foundrymen. Lancashire Branch.

Feb. 2. "Technical Records in the Foundry," by R. D. Lawrie.

Sheffield Branch.

Jan. 28. "Place of the Foundry in Industry," by F. Whitehouse.

ALMOST two years have passed since we noted with approval in these columns the formation of two panels of the British Standards Institution to prepare draft specifications for apparatus correctly designed for microchemical analysis. During at least the first half of the life of these panels, as everyone knows, meetings were difficult to arrange. Quite apart from this, we pointed out that any conclusions reached should be properly deliberated, since to specify in haste might well be to repent at leisure. However, it is not too precipitate, we think, to begin now to wonder when some results will be made known. Undoubtedly it would be reasonable—and very helpful—to follow the American example; that is, to publish results at intervals, rather than to wait for the time when the whole field will be completely surveyed. There is no reason why, for example, combustion apparatus for carbon and hydrogen should wait on the micro Kjeldahl, or why burettes might not safely be designed without undue thought for the design of filter tubes. This is a time of new activity. It is a time when we may expect many chemists to turn for the first time to the methods of microanalysis. They should be given, as opportunity permits, not only the tools for the job, but the best tools for the job.

The Microdetermination of Density

By Cecil L. Wilson

The determination of density on a small scale is of interest both to mineralogists in the investigation of gems and rare minerals, and to organic chemists as an aid to the identification of compounds. It gained extra importance with its use for the analysis of small samples of water containing deuterium oxide. It is not surprising therefore, that a wide range of methods has been developed to measure this physical property. A selection of these is reviewed in this article.

IN microchemistry, certain branches have, right from the first, received special notice from the general chemical public. Such methods as spot tests, and organic quantitative analysis may be instanced in this respect. Although these techniques have undoubtedly deserved admiration, the rather unfortunate result has been to weight them unduly in the minds of those less familiar with microchemistry, resulting in a balancing neglect of other methods which, being just as efficient and neat, only suffer from the misfortune of arriving somewhat later or less spectacularly on the scene.

Such is the case with many physicochemical methods which have been adapted to the micro scale. Certain of them are rather better known, but even in such determinations few chemists are aware of the wealth of methods or the precision of which they are frequently capable.

This is much to be regretted, because quite apart from their utility, the neatness of the methods would undoubtedly act as an excellent mental stimulant for the improvement of present, or the production of new methods. Very little study of the techniques is capable of arousing the conviction that nothing is impossible on the micro scale, given a mind sufficiently ingenious to tackle the problem. It is hardly even necessary to add a rider about technical ability of a special order, for most of the methods are surprisingly simple to operate.

Density is one of the most fundamental physical properties, and may prove, at one time or another, of importance to chemists in any branch. Many methods have been proposed for its determination on small amounts of material, and a review of suitable methods which were available up to 1926 is given by Emich[1]. Since that time many new methods have been devised, both for solids and liquids.

The density of solids is, of course, most simply determined by displacement of liquid. In the simple method of Caley,[2] a uniform tube of the shape shown (Fig. 1) is arbitrarily graduated and calibrated with water. The internal diameter is between 2·0 and 2·5 mm. A suitable liquid for the actual determination is ether. Some of this is placed in the tube, the height of the column is read with a cathetometer, the particles of the

1 Emich, *Lehrbuch der Mikrochemie*, 2nd Ed., Munich, 1926.
2 Caley, *Ind. Eng. Chem., Anal. Ed.*, 1930, **2**, 177.

solid are added, and the height is again read. The tube should be stoppered to prevent loss by evaporation. A sample weight of 50 to 100 mg. is preferable, but quite good determinations can be carried out on as little as 20 mg.

A similar method, using bromoform as the standard liquid, is described for the determination of the density of heavy solids.[3] A silica tube of 0·5 mm. bore forms the apparatus.

Blank points out[4] that Caley's method cannot be adapted to substances which must be kept whole, such as gems, because of the narrow bore of the tube. He recommends, instead, the apparatus shown in Fig. 2. A wide tube is fitted with a capillary side-arm, the latter having a bore of between 1 and 2 mm., and bearing two

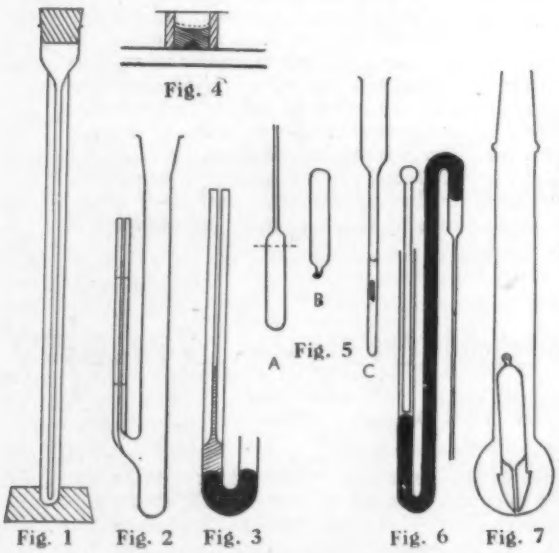


Fig. 1.—Caley's tube.
Fig. 2.—Blank's capillary method.
Fig. 3.—Blank's dilatometric method.
Fig. 4.—Microscope cell method.
Fig. 5.—Construction and use of float.
Fig. 6.—Plunger pipette.
Fig. 7.—Vacuum-filled bottle.

marks, of which the top one lies at least 3 or 4 cms. from the top of the capillary. The top of the wide tube is ground to take a weight burette (not shown). Liquid, such as ether, is added to the apparatus until the level in the side-arm reaches the lower mark. The solid is then placed in the wide tube, and the weight burette is placed in position, filled with ether. More liquid is added until the level in the side-arm has reached the top mark. The weight of ether added is determined, and subtracted from the weight required to fill the empty instrument from mark to mark. This difference enables the volume of the solid to be calculated. While ether is a very suitable liquid because it can be used with a wide range of solids, special care must be taken with it to avoid losses by evaporation.

Blank also describes[5] another apparatus whose use is evident from Fig. 3. It is based on the principle of the dilatometer. Mercury is placed in the bottom of the U, and above it in the capillary arm an inert liquid. The sample is inserted from the wide end of the tube by a coil of steel wire, which is not allowed to touch the inert liquid because of the danger of withdrawing some of it. The rise in the capillary is measured. For very accurate work, a correction should be made for the change in pressure caused by the weight of the sample on the mercury.

Winchell[6] prefers to use a pyknometer made of silica. This holds 0·13 ml. of liquid and is weighed to 0·1 mg., full of liquid, and then with the sample inserted. For small solid samples with specific gravities ranging from 4·0 to 7·5 the probable error is ± 1 per cent.

Density of solids can be determined using the microscope,[5] with an accuracy of about ± 1%. A small cell is fitted on to a microscope slide, as shown in Fig. 4, and some liquid is placed in it. The height of the liquid is noted, using the calibrated fine adjustment of the microscope, by focussing on the meniscus. The weighed solid sample is then added, and the new liquid height determined, giving the volume of the sample and hence its density. This method can be applied equally to the determination of the density of liquids which are heavier than and immiscible with the standard liquid used to fill the cell.

Flotation Methods

Flotation principles have an obvious application to the determination of the density of solids. Immersion of a particle of the solid in various liquid mixtures of high density, accurately known, will ultimately, by trial and error, arrive at a mixture in which the solid neither sinks nor floats, equivalence in density having been reached.

This basic method has been improved, particularly for dealing with minute quantities of material in finely divided form.[7] Instead of using only the force of gravity, the solid is subjected to an intensified gravitational field by centrifuging, so that it is a comparatively rapid process to determine the relation of its density to that of the liquid mixture. The density of the liquid mixture is then altered accordingly, by the addition of small amounts of lighter or heavier liquid, and ultimately a density is obtained which is accurate to ± 0·3% on 0·05 mg. or less. Air bubbles should be removed from the solid and the suspension liquid by placing in a vacuum desiccator before commencing the determination.

The determination of the density of liquids is capable of more variation, and methods devised include the use of floats, the timing of drops falling through a standard liquid, balancing a column of the liquid against a standard pressure, and finally, the more orthodox use of micro specific gravity bottles and pyknometers.

Methods depending on the use of floats have been described by a number of workers, principally for determining the density of samples or concentrates of heavy water. The float may be adjusted as in the method of Gilfillan and Polanyi,[8] filling with water so that it is just suspended, by the help of an enclosed air-bubble, in ordinary water. Or the float is balanced by a long length of capillary, which is then fused to form a keel of glass, as shown in Fig. 5. This is the method recommended by Randall and Longtin.[9] The completed float is about the size of a wheat grain, and with it the specific

3 Bannister and Hey, *Min. Mag.*, 1938, **25**, 30.
4 Blank, *Ind. Eng. Chem., Anal. Ed.*, 1931, **3**, 9.
5 Blank and Willard, *J. Chem. Ed.*, 1933, **10**, 109.
6 Winchell, *Am. Mineral.*, 1938, **23**, 805.
7 Hendricks, *J. Opt. Soc. Amer.*, 1933, **23**, 299; Bernal and Crowfoot, *Nature*, 1934, **134**, 809.
8 Gilfillan and Polanyi, *Z. phys. Chem.*, 1933, **166A**, 254.
9 Randall and Longtin, *Ind. Eng. Chem., Anal. Ed.*, 1939, **11**, 44.

gravity of as little as 0·1 ml. of liquid can be accurately determined. The float is balanced in a column of the unknown liquid, either by pressure variation[7] or temperature alteration[9] and the density of the liquid calculated. In the latter case the temperature is read by a Beckmann thermometer to 0·005° C., and a method is given for rapid calculation of the density of the specimen from the flotation temperature.

In a variant of this method,[10] two hollow glass beads with slightly different weights act as floats, the weights of the two beads bracketing the density range which it is desired to cover. The beads are contained in a 1-ml. pipette into which the liquid is drawn.

Density by Falling Drop

The falling drop method has been used to determine the density of water, as for example, in the method of Hochberg and LaMer.[11] Standard mixtures of bromobenzene-xylene with densities ranging from 0·996 to 1·108 are used in tubes 35 cms. long with a 7 mm. bore. In the plunger pipette shown in Fig. 6, the piston acts on the sample liquid through a column of mercury. The tip of the pipette is dipped under the surface of the liquid, with the unknown liquid level at the top mark. By depressing the plunger, which is

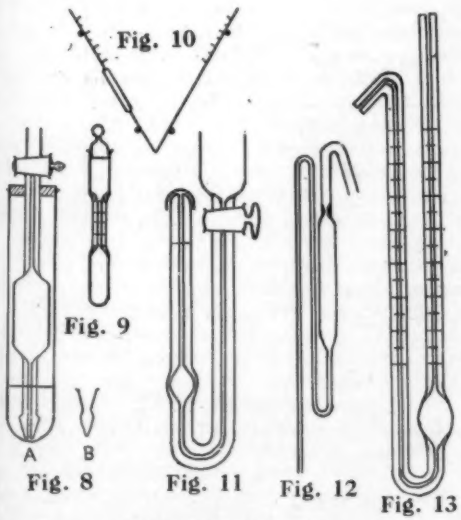


Fig. 8.—Tap bottle.
Fig. 9.—Gooderham's specific gravity bottle.
Fig. 10.—Houghton's micro pyknometer.
Fig. 11.—Fester's semi-micro pyknometer.
Fig. 12.—Constant-volume pyknometer.
Fig. 13.—Self-filling pyknometer.

loosely fitting, and greased with a mixture of resin and grease, the meniscus is brought to the lower mark, 9 cms. away. A drop is thus formed at the tip of the pipette, which may have a volume of 0·005 to 0·01 ml. By raising the pipette, the drop is loosened and is timed in its fall between two marks, to ± 0·2 second. The usual times of fall are between 25 and 70 seconds. With the data thus obtained, the accuracy of measurement of the density is ± 0·00001.

10 Mortensen, *J. Lab. Clin. Med.*, 1942, **27**, 693.
11 Hochberg and LaMer, *Ind. Eng. Chem. Anal. Ed.*, 1937, **9**, 291.

Rosebury and van Heyningen[12] describe a method which is similar in principle to that just outlined, except that a much more elaborate method is used to ensure the expulsion of drops of highly uniform size. Fetcher[13] uses a hypodermic syringe, mounted on a microscope mounting, and fitted with a threaded pin from a micrometer, in order to obtain very accurately reproducible drops.

The falling drop method has been applied to liquids other than heavy water, however, as in the determination of the specific gravity of petroleum oils.[14] Tubes containing mixtures of ethyl alcohol and water are maintained at a constant temperature, and a drop of the liquid 0·01 ml. in volume is allowed to form at the top of a capillary pipette under the surface of the standard liquid. A slight upwards jerk of the pipette releases the drop, which is timed between two marks 30 cms. apart. The pipette is calibrated to deliver a second similar drop and this is allowed to fall. The two times should not vary by more than 0·2 sec.

Specific Gravity Bottles

Direct methods of determining the specific gravity of liquids by weighing a known volume are numerous. In the method of Fontana and Calvin[15] the bottle, which is shown in Fig. 7, has a capacity of 0·8 to 1 ml. It is placed point downwards in a small flask which is then attached to a high vacuum line and evacuated to 10^{-5} mm. for 15 to 30 minutes. At a temperature about 5° or 10° below room temperature the vacuum is broken, causing the liquid in the flask to fill the bottle. Because of the shape of the tip, very little more liquid is needed than the volume actually taken by the bottle. No air bubble should be visible.

The bottle is now withdrawn, suspended tip up on the balance, and allowed to stand for about an hour. With water, for which the bottle was originally used, the liquid expands slightly, the excess evaporating at the tip, and the weight reaches a practically constant value after about an hour. The accuracy is a little worse than 0·01%.

Yuster and Reyerson[16] devised the bottle shown in Fig. 8A for the determination of the density of heavy water, in sizes varying from 0·1 to 25 mls. Liquid is placed in the test-tube up to the mark. This should allow only a very slight excess of liquid over that required to fill the bottle. The bottle is inserted in position as shown, and the apparatus is placed in a thermostat to come to equilibrium. The liquid is then drawn up carefully by suction resulting from lowering an attached levelling bulb. Care should be taken that the liquid does not pass the mark on the capillary. The tap is closed, and the bottle is removed. The slit rubber stopper is taken off. The bottle is wiped and a small glass stopper (Fig. 8B) is affixed before hanging the bottle vertically on the balance for weighing.

Gooderham[17] has proposed a specific gravity bottle for the estimation of the percentage toluene in mixed hydrocarbon fractions by determination of the density of the fractions. The bottle (Fig. 9), contains about 1 ml. of liquid and is filled by means of a capillary pipette which is fitted with a calcium chloride tube to prevent contamination with water from the mouth.

12 Rosebury and van Heyningen, *ibid.*, 1942, **14**, 363.
13 Fetcher, *ibid.*, 1944, **16**, 412.
14 Hoiberg, *ibid.*, 1942, **14**, 323.
15 Fontana and Calvin, *ibid.*, 1942, **14**, 185.
16 Yuster and Reyerson, *ibid.*, 1936, **8**, 61.
17 Gooderham, *J.S.C.I.*, 1944, **63**, 65.,

Pyknometers

Houghton's micro pyknometer[18] for 0·01 ml. or less of liquid has already been described in these columns.[19] It is shown in Fig. 10.

The semi-micro pyknometer of Fester[20] holds about 0·5 ml. The liquid is placed in the cup (Fig. 11) and by careful adjustment of the tap is allowed to flow into the

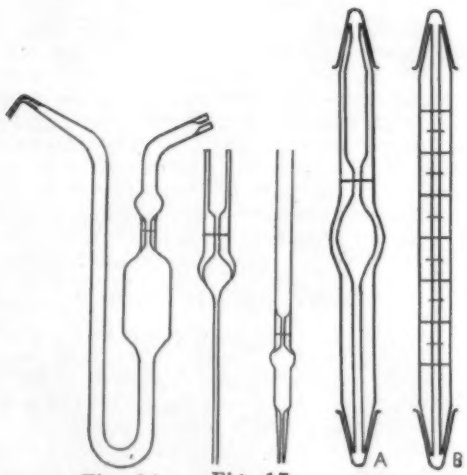


Fig. 14 Fig. 15 Fig. 16

Fig. 14.—Hennion's self-filling instrument.
Fig. 15.—Pipette pyknometers.
Fig. 16.—Straight-tube pyknometers.

other arm slowly, till it just reaches the calibration mark. The tap is then closed and the cup is dried with filter paper. The ground cap on the open limb prevents evaporation.

Hahn has applied the principle of constant volume delivery to both pipettes and pyknometers.[21] A capillary constriction (Fig. 12) ensures that because of surface tension the meniscus will always stop at the same point. Liquid is drawn in by suction till it rises above the constriction. On allowing it to flow out it is caught at the constriction. The tip is wiped and the pyknometer is hung in an inverted position on the balance. In this way, the liquid runs back a little from the tip, effectively preventing evaporation.

Although the accuracy of such a device might be doubted, tests showed that the accuracy of the volume held in a 1 ml. pipette was ± 0·00005 ml. over a series of determinations. This means that unless the temperature is controlled to within ± 0·2° C., the temperature error will be greater than the weighing error.

A self-filling pyknometer, specially suited to volumes of 5 mls., can also be made in 0·3, 1 or 3 ml. sizes.[22] It is shown in Fig. 13. A hook tip acts as a filling device, first through capillary action, followed by siphoning. The capillary has a bore of 0·6 to 1 mm. and 8-cm. lengths on each limb are graduated in cms. and mms. The vessel is calibrated with water, a graph being drawn connecting the sum of the lengths on both arms with the actual volume obtained. The instrument is claimed to be accurate within ± 0·0001 g. per ml. of volume.

Another self-filling pyknometer described by Hennion[23] has a capillary tip of 0·75 mm. bore, and is made of tubing of 2-mm. bore (Fig. 14). The bulbs may be made of various sizes to accommodate 0·75 to 10 ml. liquid. On dipping the hook under liquid with the finger pressed over the other end, and then releasing the finger, liquid is drawn along the capillary which passes round the bend and then siphons over and fills the pyknometer to the graduation mark.

The finger is once more replaced to stop further filling. By tilting the pyknometer the liquid now runs back from the tip and the apparatus is then hung in the balance case and subsequently weighed.

The pyknometers recommended by Pregl[24] are simply micro-pipettes which are first weighed empty, then filled to the mark and reweighed. Two types are illustrated in Fig. 15. It is stressed that care should be taken not to draw the liquid up more than 1 mm. or so past the mark, as otherwise drainage errors will be so great that it is preferable to empty, dry and refill the instrument.

A similar pyknometer, bearing graduations along the stem, is described by Fürter.[25]

Straight-tube pyknometers, about 10 cms. long, have also been recommended by Alber,[26] who reviews a range of methods. Such a pyknometer as that shown in Fig. 16A, which takes a volume of 0·1 ml., gives an accuracy of 0·05%. A pyknometer with a straight capillary, taking a volume as low as 6 cu. mm., such as that shown in Fig. 16B, may have an accuracy of ± 1%. Pyknometers of this type, as in other instances already mentioned, may have graduations along the whole or part of the stem, being then calibrated so that filling to one precise mark is not essential.

These pyknometers are fitted with ground-glass cap stoppers to minimise evaporation errors.

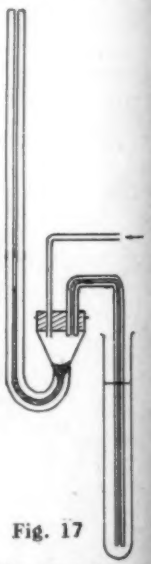


Fig. 17

Fig. 17–Balanced-column apparatus.

The Balanced Column

Finally, a mention should be made of the method, described by Blank,[5] which depends on balancing a liquid column. The apparatus, shown in Fig. 17, is immersed in a thermostat and a small volume of the unknown liquid is placed in the conical vessel. The pressure in the system is adjusted by suction from an aspirator to a constant value. This is best achieved by adjusting it to give a fixed bubble rate in the bubbler, for example, 60 bubbles per minute. The height to which the liquid rises in the capillary, corrected for capillary rise effect, is then inversely proportional to the density of the liquid.

18 Houghton, *Analyst*, 1944, **69**, 345.
19 METALLURGIA, 1945, **31**, 154.
20 Fester, *Chem. Fabrik*, 1933, **6**, 509.
21 Hahn, *J. Chem. Ed.*, 1944, **21**, 246.
22 Lipkin, Davison, Harvey and Kuntz, *Ind. Eng. Chem., Anal. Ed.*, 1944, **16**, 55.
23 Hennion, *ibid.*, 1937, **9**, 479.
24 Pregl-Roth-Daw, *Quantitative Organic Microanalysis*, 3rd English Ed., London, 1937.
25 Fürter, *Helv. Chim. Acta*, 1938, **21**, 1674: Belcher and Godbert, *Semi-Micro Quantitative Organic Analysis*, London, 1945.
26 Alber, *Ind. Eng. Chem., Anal. Ed.*, 1940, **12**, 764.

Copper-Base Compacts and Certain Compositions Susceptible to Precipitation-Hardening

By F. R. Hensel, E. I. Larsen and E. F. Swazy

HIGH strength, high conductivity copper-base alloys have found considerable use in the resistance-welding and electrical industry in the form of castings, forgings, or wrought products. There are a number of parts used by these industries which lend themselves to manufacture by powder metallurgical methods provided the required physical and electrical properties are obtainable with such methods. The results are given of an investigation of certain copper-base powder metallurgical products susceptible to precipitation hardening.

The type of powder used during the investigation was electro-lytic powder having a screen and chemical analyses as shown in Table I. In the preparation of compacts of high electrical conductivity, the purity of the copper powder is important in addition to other factors such as density and the state of internal stresses. These variables were studied by pressing a number of compacts to various pressed densities, sintering them for one hour in hydrogen at 975° C. and repressing. Curves of pressed density versus compacting pressure and sintered density versus compacting pressure show direct relationship of pressure and density. Variations in the initial pressed density within the range of about 5 to 6 grams per cc. affect only slightly the pressure required to obtain a given repressed density after sintering. The relationship of hardness versus density, after sintering and repressing, shows that the greater amount of cold-working received by the samples of lower initial density results in a higher final hardness when repressed to identical densities. The initial (pressed) density before sintering and repressing has a drastic influence upon the ultimate tensile strengtn. With decreasing initial density the tensile strength increases. The material having the lowest initial density has also the lowest electrical conductivity, caused probably by the greater amount of cold-work necessary to repress it to given density.

Pressing within the temperature range of 25° to 600° C. indicated that optimum values of density and hardness were obtained at temperatures in the neighbourhood of 400° C. A series of tests carried out at this temperature showed the density to increase with compacting pressure and to obtain its maximum at a pressure of 40 tons per sq. in. A further increase in pressure to 65 tons per sq. in. caused only a slight increase in density. The hardness values of 65 to 72 Rockwell B obtained in hot-pressed copper compacts with a density of 8·75 to 8·8 grams per cc. were 97·5% of the theoretical value of 8·93 grams per cc. and were higher than could be obtained in cold-worked wrought copper. The annealing temperature of hot-pressed copper compacts was higher than that of cold-worked commercially pure copper and showed little loss in hardness up to an annealing temperature of 300° C.

A series of compositions was investigated to determine the susceptibility of precipitation hardening copper-base compacts to heat-treating after pressing, sintering and repressing. Compacts of sufficient size were processed to allow the machining of standard 0·505 in. diameter tensile test specimens. The pressures used in pressing and repressing were of sufficient magnitude to produce a final density equal to 95% that of the theoretical density for each alloy. It was found necessary to carry out all high temperature heat-treating operations (sintering and solution) in a hydrogen atmosphere, as compacts treated in air did not respond properly to the precipitation treatment because of the

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TABLE I.—TYPICAL SCREEN AND CHEMICAL ANALYSIS OF ELECTROLYTIC-COPPER POWDER.

Apparent Density 2·5 gm. per cc.		Chemical Analysis %	
Mesh Size	% Retained		
100	0·0– 0·2	Iron	0·25
150	1·0– 3·5	Zinc	0·10
200	5·0– 9·0	Oxygen	0·25
250	1·5– 3·5	Copper	Balance
325	15·0–20·0	—	—
−325	65·0–75·0	—	—

TABLE II.—COMPOSITION AND PHYSICAL AND ELECTRICAL PROPERTIES OF PRECIPITATION-HARDENING COPPER-BASE COMPACTS.

Alloy	Chemical Composition						Ultimate Stress Tons per sq. in.	Elongation % on 2 in.	Electrical Conductivity as Solution Treated %	Electrical Conductivity After Ageing %	Hardness as Repressed Rockwell B	Hardness as Solution-Treated Rockwell F	Hardness as Aged Rockwell B
	Ni	Cr	P	Be	Others	Cu							
L 1503.. ..	1·0	—	0·25	—	—	Bal.	—	—	22·3	30·0	22	25	20
L 1504.. ..	2·0	—	0·5	—	—	Bal.	20·1	4	21·9	40·0	19	36	53
L 1505.. ..	—	—	0·25	—	0·75 Mn	Bal.	—	—	24·4	44·1	33	45	14
L 1506.. ..	—	—	0·15	—	0·5 Mn	Bal.	—	—	32·2	55·6	44	26	44
L 1507.. ..	4·0	—	—	—	4·0 Sn	Bal.	—	—	11·7	12·8	42	30	35
L 1508.. ..	5·0	—	—	—	8·0 Sn	Bal.	—	—	7·25	8·1	46	15	40
L 1509.. ..	—	3·0	0·5	—	—	Bal.	—	—	—	—	—	38	53
L 1510.. ..	—	3·0	0·1	—	—	Bal.	21·5	7	32·2	64·3	35	38	51
L 1511.. ..	—	3·0	0·1	—	0·5 TiH_2	Bal.	23·2	8	33·5	69·1	38	42	68
L 1512.. ..	—	—	0·5	—	2·0 Co	Bal.	16·3	15	28·5	43·1	30	28	39
L 1271* ..	2·5	—	—	0·5	—	Bal.	23·2	7	—	61·0	35	—	72
L1271–A* ..	2·5	—	—	0·5	—	Bal.	17·6	5	—	52·0	35	—	60
L 1272.. ..	3·0	—	—	0·5	0·5 Si	Bal.	27·3	2·5	—	35·5	35	—	80
L 1293* ..	—	—	—	0·5	2·5 Co	Bal.	34·9	3·1	—	41·0	35	—	85

* Prealloyed Powders of Co and Be or Ni and Be were used.

oxidation of all or a major portion of the precipitating constituents. The composition of the compacts and their physical and electrical properties are given in Table II.

The data obtained indicate that manganese-phosphorus and nickel-tin additions to copper did not produce appreciable precipitation-hardening effects. Promising results were obtained with the addition of nickel-phosphorus, chromium, cobalt-phosphorus and the nickel-beryllium and cobalt-beryllium alloy powders. The highest tensile properties were obtained with the copper-cobalt-beryllium compact L-1293, and the greatest ductility after complete heat-treatment was found in L-1512. The results of Krouse rotating beam fatigue tests on alloy L-1511 indicated a fatigue strength of 9 tons per sq. in. Detailed studies of the ageing characteristics did not reveal any phenomenally different from those of wrought alloys. It was found, however, that the compositions under investigation had a decreased tendency towards over-ageing.

Because of the formation of a soft shell or layer on copper-alloy compacts containing beryllium, even though the compacts were sintered in relatively pure hydrogen, attempts were made to eliminate or decrease the thickness of this layer by the addition of phosphorus. Four alloys were investigated, two containing copper, cobalt, beryllium and phosphorus and two containing copper, nickel, beryllium and phosphorus. From the results obtained, it was found that the addition of approximately 0·2 to 0·3% phosphorus greatly reduced or retarded the formation of a soft shell and that phosphorus additions within the range tested did not adversely affect the precipitation hardening characteristics. Titanium hydride was also found to be beneficial in such alloys.

A New Microscopy and its Potentialities

By C. S. Barrett

A NEW microscopy, which is of potential value in physical metallurgy and other fields, involves X-rays, but does not make use of the usual accompaniments of X-ray research, such as reciprocal lattices, Fourier series or the stereographic projection. The development of this new method followed on earlier work which showed that it was possible to map out the distribution of strains over the surface and through the interior of a crystal by observing the internal structure of the X-ray reflections. Experiments first on crystals of rock salt and then on single crystals of silicon ferrite, showed that micrographs of metals, which would show changes induced by deformation, could be prepared by X-ray diffraction. To obtain such micrographs it was necessary to use fine-grained photographic emulsions that would stand great enlargements and to prepare crystal surfaces free from scratches and flowed metal by using electrolytic polishing.

The essential elements of the method are a fine-grained photographic plate placed in contact or very close to the specimen to be examined and a beam of characteristic X-rays striking the specimen. In the X-ray camera for single crystals, the beam coming from the left passes under a metal shelf on which the photographic plate rests, emulsion side down. The crystal fits up against the under-side of the plate and is turned into a reflecting position in the beam by a suitable arrangement, the adjustment being made while watching a fluorescent screen placed above the crystal. For polycrystalline material, it is only necessary to have a cylindrical specimen resting against the photographic plate and supported by a simple L-shaped metal housing, which also serves to catch the rays not stopped by the specimen. Images formed on the plate by diffraction can be enlarged by useful magnifications up to 100 or perhaps to 250 diameters. The conditions for good images are as follows:—(1) a specimen surface undistorted by sawing or polishing; (2) a minimum distance from specimen to plate; (3) an X-ray tube with target of low atomic number emitting characteristic radiation; (4) a plate with high resolving power (fine grain) shielded from the direct beam; (5) examination or enlargement of the plate with good lenses, using transmitted light.

The X-ray diffraction micrographs obtained show the places where inhomogeneous strain is concentrated. Along planes where slip has occurred throughout the interior of crystals or polycrystalline grains, there is a local bending or rotation of the crystal lattice. This increases the efficiency of X-ray reflection and causes a dark line on the photographic plate. Combined with goniometer measurements, micrographs show that local rotation at slip lines is less than 0·1° in slightly deformed ferrite and is confined to a layer 3 microns thick or less, whereas rotation at the boundaries of deformation twins formed by simple tension in a single crystal of silicon ferrite lies in the range 0·5° to 1°. In similar examination made of the rotation induced by scratching a silicon ferrite crystal with the point of a needle, clear-cut images of the scratches were obtained and the amount of fragrant rotation at the scratch was found to lie between 5 and 10 minutes of arc.

In the application of the new method to strain-free polycrystalline metals, the sizes and shapes of polycrystalline grains are well shown. Irregularities on the surface, such as etch pits, show clearly when they cast shadows in oblique radiation. A small amount of plastic deformation causes a fragmentation of the image of each grain into an assemblage of dots, presumably representing microstrain peaks and perhaps grain fragments. Deformation bands can be recognised in the images of grains, as well as deformation twins, annealing twins, including grains, and distortion from scratches and cutting tools. Higher deformations produce long streaks in which internal detail cannot be resolved and ultimately destroys all images.

Micrographs from experiments on deformation resulting from tensile tests on commercial aluminium, on a low ferritic alloy (0·83% chromium in iron) and on high purity aluminium of two different grain sizes, have shown that the cold-worked structure persists throughout the recovery period during annealing, and disappears only when it is absorbed by strain-free recrystallised grains. There is a striking difference between images of recrystallised and uncrystallised grains, which make X-ray micrographs of value in recrystallisation investigations.

X-ray diffraction micrographs are also of value in investigating inhomogeneous strains in cast metals. Experiments on aluminium (99·9% purity) and on high purity magnesium, clearly show the imperfections of cast grains not only in alloys where coring is present, but also in pure metals. Micrographs of pearlite formed at 700° C. in a 0·7% carbon steel and of an alloy of indium and tin (50·7% tin) show clusters of similarly oriented crystals in the eutectoid and eutectic

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of those polyphase alloys. By measuring the direction of the diffracted rays from individual microconstituents, the new method provides a means of identifying them, and also makes microanalysis possible on individual particles.

In the examination of strains from age-hardening, micrographs from experimental work carried out on an alloy of copper containing 1·92% beryllium after a negligible ageing time in an isothermal bath at 240° C. and on an aluminium-silver alloy containing 30% silver, show a fragmentation of the grain images much like cold work and a blurring of diffraction spots. Recrystallised areas that form along grain boundaries during cold work are seen, together with evidences of strain adjacent to the recrystallised area, and thereby lend support to the conception that the increase of hardness in age-hardening is almost wholly due to microscopic internal strains at the interface between the precipitate and the matrix during the early stages of growth of the precipitate.

When an alloy changes from the random arrangement of atoms on lattice points that is known as a solid solution to the ordered array that is called a superlattice, there is profuse distortion, particularly when a change of lattice symmetry accompanies ordering. The superlattices capable of the greatest hardening by heat-treatment are the ones in which a change of crystal lattice accompanies ageing, and it is in this class of super-lattice that alterations in the X-ray micrographs can be predicted with some confidence.

Ammonia for Processing Metals

By E. R. Woodward and R. J. Quinn

THE use of ammonia in the metal industries both as a furnace atmosphere and as a source of pure hydrogen has expanded greatly during recent years. Nitriding and dry cyaniding use anhydrous ammonia as such, and in these processes the conditions in the furnace are controlled to produce the required proportion of dissociation. In other processes, such as bright annealing, nitriding of stainless steel or sintering of powdered metals, dissociation of ammonia must be carried out before the gases enter the furnace. Where hydrogen is required, as in welding, anhydrous ammonia yields a purer gas upon dissociation than is obtained from other sources. Dissociated ammonia may also be burned in the gas converter to produce 99·5% pure nitrogen.

The particular advantages of ammonia for many special industrial applications are its purity, the absence of moisture, ease of dissociation and economy. A cracking equipment or ammonia dissociator, when operated at rated capacity, gave 99·5% dissociation of which 25% by volume was nitrogen and 75% hydrogen. If pure nitrogen is required the hydrogen may be burned and condensed out as water. Moisture in the furnace atmosphere causes decarburisation. In commercial practice, it has been found that a furnace atmosphere is reasonably dry when the dew point is below −50° F. and as dissociated anhydrous ammonia gives a gas mixture with a dew point below this temperature, it is therefore entirely suitable for use in metal-treating operations.

The nitriding process of hardening requires accurate temperature control over the range 450° to 650° C. and the use of special alloy steels. Low temperatures produce a thin, hard case, while higher temperatures produce a deep but softer case. The depth of the case varies with the length of the nitriding cycle, which may range from 20 to 100 hours. For chromium-aluminium-molybdenum steels, a 50-hour cycle will give approximately 0·015 in. case of which 0·005 to 0·007 in. exceeds 900 Vickers hardness. With a 100-hour cycle, the case depth is approximately 0·03 in. with 0·01 to 0·012 in. in excess of 900 Vickers hardness. Upon completion of the nitriding cycle, the ammonia is allowed to flow until the container holding the metal parts has cooled to 200° C. In Table I, are given the composition of some nitriding steels and the results obtained from them.

Dry cyaniding, carbo-nitriding or nicarbing, is a combination of the continuous process of nitriding and gas carburising. The carbo-nitrided case has approximately the same corrosion resistance as the nitrided case, while comparing favourably in hardness with the carburised case. The effect of ammonia, which may be used in conjunction with a variety of carburising gases, on the carburising reaction is very marked, permitting carburisation at lower temperatures than usual. For duplicating the usual cyanide case, general practice is to add a very small amount of ammonia gas to an atmosphere suitable for light case carburising at hardening temperatures, whereby a higher carbon content is obtained suitable for oil quenching. Air-hardening properties are imparted to straight carbon or low alloy steel parts by increasing the amount of ammonia and this variation in the process has been applied to parts which distort on quenching.

In the surface hardening of stainless steels, the outer layer of the metal is impregnated with nitrogen, presumably in the form of nitrides to a depth that varies with the type of steel and the time it is under treatment. The process is carried out at 540° to 600° C. and surface hardness up to 1,050 Vickers hardness are obtained. The furnace gas is derived from anhydrous ammonia and is used in two states. During the preliminary part of the cycle the ammonia vapour is dissociated and after purification and activation it is admitted to the nitriding chamber to sweep out all traces of air that may be present. After this preliminary purging, ammonia vapour, which has first been ionized in a silent electrical discharge, is admitted to the nitriding chamber.

From *Metals and Alloys*, 1945, Vol. 22, No. 2, pp. 418-424.

TABLE I. COMPOSITION AND TESTS ON SOME NITRIDING STEELS.

Steel	Composition									Nitriding Tem. °C.	Nitriding Time Hours	Vickers Hardness 10 kg.	Depth of Case In.	Core Hardness Rockwell C
	C	Ni	Co	Cr	Mo	W	V	Si	Al					
A	0·53	—	—	3·65	0·51	—	0·74	—	—	525	72	975	0·018	47
B	1·50	—	—	12·11	0·94	—	0·94	—	—	540	48	1,150	0·012	59
C	1·33	0·55	3·08	13·31	0·81	—	—	—	—	540	72	970	0·012	50
D	0·77	—	—	3·83	8·63	1·35	1·01	—	—	540	72	1,400	0·015	63
E	1·2/1·3	—	—	1·0/1·25	—	4·75/3·25	0·15/0·25	—	—	540	48	925	0·008	56
F	1·04	—	—	1·25	1·33	0·51	0·25	—	—	540	48	975	0·018	47
G	0·37	0·23	—	4·92	1·32	—	0·44	1·06	—	480	48	1,100	0·014	43
Nitraloy	0·25	3·54	—	1·11	0·30	—	—	—	1·30	525	35	1,064	0·016	44

In the actual nitriding process, ammonia gas is partly dissociated, the nitrogen is absorbed by the material and the hydrogen that is released passes out of the furnace with the undissociated gas.

Pure hydrogen which is used successfully for the bright annealing or normalising of steel parts and is also applicable to the heat-treating of non-ferrous metals, has a high cost, and as an alternative and cheaper source of reducing atmosphere, dissociated ammonia gas is well suited for certain types of work, and in many metallurgical operations, the presence of a proportion of inert nitrogen is advantageous. In copper brazing also, the best gas to produce a reducing atmosphere in copper brazing furnaces is pure dry hydrogen, but it has been found more economical to use dissociated ammonia. While hydrogen is an excellent atmosphere in powder metallurgy furnaces, it is too expensive for most commercial sintering operations, and dissociated ammonia may be used as a high hydrogen atmosphere or it may be burned in the gas converter to give a commercially pure nitrogen atmosphere. The use of dissociated ammonia also shows substantial savings in the atomic hydrogen and oxy-hydrogen arc welding processes when the user's total demand for hydrogen averages 50 cu. ft. per hr. or more.

Ultra-Violet or Black Light Inspection of Aluminium Castings

By E. V. Blackmun and E. Bremer

ONE difficulty encountered in the detection of dross films and surface cracks in aluminium and magnesium alloy castings is the lack of sensitivity of inspection procedures. One of the oldest methods employed for the purpose was to soak the castings in kerosene, low grade petrol or light machine oil, wash with a suitable solvent, and dust with chalk, talc or whiting. The oil was retained in the fine cracks and porous areas, and was absorbed by the chalk or whiting, showing up as damp or wet spots which could be detected visually. The sensitivity of this method, however, is deficient because of the lack of contrast between the dry and wet whiting or chalk on the surface of the piece.

A new testing method, similar in principle to the old one, but which achieves a major increase in the sensitivity and brilliance of the indications, involves the use of a fluorescent oil penetrant, and near ultra-violet or black light. Using this method, the parts to be inspected are immersed in the oil for several minutes, removed, drained and washed, and then dusted with a light coat of talc which withdraws and absorbs the fluorescent oil from the surface discontinuities and provides optimum conditions for examination of the part under near ultra-violet light. The fluorescence which appears as the result of this method is quite intense and exhibits a high degree of contrast between those surface imperfections which retain oil, and the sound surface which does not hold oil. Contrast as measured by a photometer is approximately 2,000 to 1 as compared with the greatest contrast between black and white which is not more than 100 to 1.

The principal quality required of the fluorescent oil is that it has good penetrating characteristics, and, since penetration is accompanied through capillarity involving wetting ability and surface tension of the material, an oil with a very low contact angle and a strong affinity for metals is preferable. Many mineral oils fluoresce and their degree of fluorescence under ultra-violet light is in proportion to their viscosity. Heavy oils fluoresce more intensely than light oils but have poor penetrating characteristics unless heated. An oil solution of a soluble fluorescent dye fluoresces more highly than heavy oil alone. Soluble oils are also particularly suitable as penetrating solvents and are readily removed by washing with water.

In inspection, small castings in baskets are usually immersed in the oil solution for at least 10 minutes, and large parts are either painted or sprayed. After draining, excessive oil is removed by high-pressure water spraying especially with sand castings. Die castings and permanent mould castings may be washed satisfactorily with cold water, but high pressure spraying is preferred. After washing parts are dried in air and talc powder is applied by dusting or rolling the part in the powder to provide a thin surface layer. Inspection with near ultra-violet light from mercury vapour argon glow or fluorescent and incandescent filament lamps is best carried out in a darkened room with visible light limited to that required for the handling of parts. Permanent records of fluorescence can be made comparatively easily by the use of high speed, colour sensitive films.

From *The Foundry*, 1945, Vol. 73, No. 5, pp. 96–99.

Fine Wire of Special Materials

By R. L. Zahour

RAPID strides in the development of electronic devices have stimulated the demand for fine wire in sizes ranging from 0·002 to 0·0007 in. and even smaller in diameter, depending on the material and its use. Fine platinum wire employed for precision fuses to protect delicate electrical instruments is even made in sizes down to 0·000017 in. diameter, and precision resistors for radio and communication equipment call for fine nickel alloy resistance wire manufactured to very close tolerances in diameter and in ohms per unit length.

Several critical factors must be considered when fine wire is drawn smoothly and uniformly round to close physical and electrical tolerances. Generally these factors are :—(1) selection of lubricant and diamond dies; (2) careful regulation of drawing speeds and annealing processes; and (3) accurate determinations of draft (reduction of diameter). Accurately drilled and polished diamond dies, perfect in every detail, are carefully selected for the type of metal or alloy wire to be drawn. For drawing hard alloy wire, the die selected must have a long channel while for softer metals, the die chosen must have a short channel. To prevent rapid die-wear during the drawing process, the proper lubricant for the kind of wire to be drawn has to be selected. Sometimes, fatty or heavy oil emulsions are used and sometimes light lubricants such as soap and water are constantly applied. All lubricants must be chemically inert so that nothing will mar the high lustre produced by the die on the wire surface.

From *Metals and Alloys*, 1945, Vol. 22, No. 2, pp. 403–407.

For some types of fine wire the draft or reduction in diameter of a wire can be as small as 0·00015 in. It is possible to draw on one machine from 0·0046 in. to 0·0012 in. at a speed of nearly 3,000 ft. per min. The tolerable reductions, however, vary depending on the hardening characteristics of the alloy. Some alloys harden faster and create more heat and die-wear than others as they pass through the dies, so that hard alloys must be drawn at speeds slower than those for soft ductile metals. Drawing speeds therefore, vary from 100 to 5,000 ft. per min., the correct speed for a given wire being largely based on experience. Some alloys harden quite rapidly after passing through a few dies and must be annealed in a reducing atmosphere under careful and accurate temperature control.

In checking permissible tolerances, accurate measurements on fine wire are made by weight rather than by actual diameter in inches using a precision torsion balance calibrated in 0·01 of a milligram. Tensile strength and percentage elongation characteristics are measured on a special precision testing machine. The resistance of fine wire alloys, used in the manufacture of precision resistors in electronic devices, must be kept within specified tolerance measurements in ohms per linear foot, and such are carefully measured on a Wheatstone bridge. To examine the crystalline structure and to obtain a complete picture of the atomic arrangement in wire metals X-ray diffraction is used.

Recent Experiences in Sintering

By Birger Hessle

IN the introduction the author discusses the advantages derived from the use of iron ore sinter in blast-furnace charges in Sweden; these are principally :—

A lowering of the consumption of fuel in blister steel blast-furnaces; a considerable increase in the production per furnace unit; the ability of the mines to dispose of low-percentage ores which would otherwise have been largely left on their hands.

About 900,000 tons of sinter were manufactured from Swedish raw materials in 1939. The problems of sintering are examined from the point of view of the use of sinter in charcoal blister steel blast furnaces, except where otherwise stated.

The chemical properties required in sinter for use in charcoal blister-steel blast-furnaces are :—

(1) High iron content.
(2) Low content of deleterious substances such as sulphur and arsenic.
(3) Low content of difficulty reducible ingredients such as iron silicates, etc.
(4) High degree of oxidation to facilitate indirect reduction.
(5) Uniform composition, so that special slag formers need not be supplied to the blast-furnace.

The physical properties required are :—

(1) Adequate mechanical strength to ensure that the sinter is not broken up too small during crushing and transport.
(2) Adequate strength to resist the conditions prevailing in the blast-furnace.
(3) High microporosity to facilitate indirect reduction.

A number of factors are listed which affect the sintering process, namely :—

Ingredients of charge :—

Chemical analysis; degree of oxidation; nature of the gangue; screen analysis; grain form.

Fuel :—

Type; chemical analysis: ash content and chemical composition of the ash; moisture content; screen analysis; quantity.

Mixing :—

Mixing process; moisture content; physical characteristics.

Charging and sintering :—

Manner of charging; shape of pan; ignition; negative pressure; amount of air flowing through under suction; duration of sintering; supervision of charge.

The author distinguishes between two types of sinter, which he describes as "rush-burnt" and "black-burnt," respectively. The former has been subjected to vigorous and the latter to less vigorous thermal treatment. Good black-burnt sinter possesses a higher degree of reducibility and of mechanical durability than the "rush-burnt" variety.

Illustrations show the temperature curve throughout the sintering process for both types of sinter, and divide the process into zones, of which No. 1 is that nearest the grate surface and No. 10 (the last) the stratum nearest to the surface of the charge; in this connection a diagram shows the distribution of temperature through the load at a given moment.

In zones 1 and 2 there is an almost constant temperature, the moisture not yet having been expelled. The hot gases from zone 4 rapidly evaporate the moisture in zone 3. Zone 4 is the pre-heating zone, in which the charge is brought to the ignition temperature of the fuel by the hot gases from the combustion zone, zone 5. Here the load is an incandescent powder without appreciable fritting or binding characteristics. In this zone there is reduction of Fe_2O_3, but practically no oxidation of Fe_3O_4. Zone 6 is the first oxidation zone, where a part of the Fe_3O_4 is oxidised to Fe_2O_3, with rising temperature. Zone 7 is the equilibrium zone, with comparative equilibrium between Fe_2O_3 and Fe_3O_4. Zone 8 is the second oxidation zone, where further oxidation of Fe_3O_4 to Fe_2O_3 takes place. Zone 9 is the cooling zone, and in the final zone, No. 10, constant conditions prevail.

A diagram shows how the applied heat is used up in the process to make up for heat losses, and the author describes various methods of reducing the heat losses due to radiation during ignition, heat expended on the expulsion of moisture and the heat remaining in the sinter and the rejected portion of the load. Two other sources of heat loss, namely, the physical heat in the waste gases and the heat required for splitting up the carbonates, can hardly be remedied. In this connection the mutual effects of varying the fuel, moisture content, quantity of air and quantity of fuel are examined in detail and illustrated by graphs. Various methods of modifying these factors are given.

The production of good "black-burnt" sinter demands that a certain sintering temperature shall be attained, but not exceeded, and that the period of time at and immediately below that temperature shall be short, and in order to ensure the fulfilling of these conditions attention must be paid to :

(*a*) Even mixing of the charge.
(*b*) Loose and uniform charging.
(*c*) Simultaneous and uniform ignition.
(*d*) The fine crushing of the fuel; and
(*e*) the maintenance of a plentiful air supply.

From *Jernkontorets Annaler*, 1945, **129**, No. 8, 383-416.

In connection with these requisites, methods of overcoming practical difficulties are dealt with, and the design of the charging gear and the ideal shape of the sintering pan are discussed and illustrated; a special type of pan lining which is designed to prevent the appearance of fret-holes at the edges of the grates, and which is in use at Hofors, is explained. From a loading point of view, rectangular pans are to be preferred to round ones; the advantages of loose charging have hitherto been obtained in sintering plants which have rectangular pans. A diagram is provided of a charging device for the loose charging of round pans, however, recently installed at Hofors. The important point to watch with regard to the shape of the pan is that the risk of leakage and of fret-holes in the charge should be eliminated.

Formulæ are supplied for calculating the negative pressure required for ensuring the flow, under suction, of a given quantity of air through the sintering charge in a given unit of time, and measures are described for reducing as far as possible the resistance to air flow offered by the moist mixture in the pan, a resistance which alters, however, as soon as the charge is ignited.

The type of fuel to be selected for ignition purposes and for admixture to the charge is discussed. For ignition purposes there is the choice between solid fuels (such as coke dust, charcoal dust, sawdust, etc.), fuel oil and, thirdly, gaseous fuels. Solid fuels present certain difficulties as regards even distribution to ensure simultaneous ignition at all points, but gases and oils, though requiring special apparatus for ignition, offer numerous advantages, such as simultaneous ignition and extinction over the whole area, and the fact that they do not form clogging ash.

For admixture to the charge, coke dust, charcoal dust, or a mixture of both is usually employed. According to Greenawalt, fuels containing gas are not suitable because part of the gas escapes without combustion, and because they can condense and close up the pores in the lower portion of the charge.

The author examines the mechanics of the fritting process. A particular temperature, and oxidising conditions, are required, and loosely-packed charging is preferable to tighter packing; it yields a more compact sinter.

Microphotographs of sinter from charges subjected to differing conditions during production illustrate the three main types of oxidation observed; octahedral plane oxidation, edge oxidation and grain-field oxidation are the descriptions applied to them by the author, who examines the causes of each. The author discusses the rôle of slag formation in the sintering process, and the influence of the degree of oxidation on the quality of the sinter.

In the production of good "blackburnt" sinter, the sulphur content should be brought down to a very low level, and the author affirms that fears sometimes expressed that the addition of lime to the mixture would bind the sulphur in the sinter by the formation of sulphates are not borne out in practice. The addition of lime has, in most cases, yielded an increase in production and, at the same time, a reduction in the fuel admixture required. At Domnarvet, for instance, a reduction of two minutes in the time required for sintering, and a saving of about 22 lb. of coke dust per ton of sinter, were observed. The reason seems to be that the charge, during the sintering process, offers less resistance to flow. Slaked lime is quicker than pulverised limestone.

For the guidance of both workers and management, certain checks or tests are necessary, and these the author lists as follows:—

(1) *Mixing:* Moisture content; quantity of fuel; screen analysis.

(2) *Sintering process:* Waste gas temperature; negative pressure; temperature curve in the charge.

(3) *The sinter:* Weight of sinter per pan; screen analysis; sulphur content; degree of oxidation.

The author describes methods used for carrying out these tests.

The economy of the blast-furnace process (particularly as regards coal consumption) is in a high degree dependent on the characteristics of the sinter. A modification of the sintering plant in accordance with the principles outlined by the author can, even if the sintering costs are not reduced, yield various economies, including the saving of coal in the blast-furnace, and thus step down production costs. It has, however, been observed that, in general, the measures described by the author yield considerable economies in the sintering plant itself. The author quotes examples of reduced costs of sinter (e.g., from 4·15 kronor to 3·10 kronor per ton) through rebuilding existing Greenawalt and AIB types of sintering plant.

Translated and digested by Mr. J. E. Radcliffe, A. I. L., Woodlands Cottage, Southwell Road East, Rainworth, Mansfield, Notts.

Indium

IT was in 1863 in the old city of Freiberg, nestled in the foothills of the Saxon Erzgebirge (famous for its wide variety of mineral deposits), that Professor Ferdinand Reich and his assistant Hieronymus Theodor Richter were examining a group of minerals with the aid of the spectroscope when they came upon a specimen of sphalerite that showed brilliant indigo blue lines never before observed. Upon further testing they soon were convinced that the blue lines were due to the presence of a new element which they christened "indium." The indium spectral lines are quite distinct from the two blue lines of cesium and the blue line of strontium. The indium blue can be recognised even without a spectroscope by merely heating a little indium chloride on a platinum wire in the bunsen flame. Reich and Richter were also the first to isolate the metal. They reduced a sample of indium oxide with charcoal and obtained a small button that looked very much like tin.

Indium occurs in sulphidic ores as well as in oxidic ores. An interesting occurrence of indium is that of the silver-bearing sulphostannates of Bolivia. Indium is present in all zinc blends and in contradistinction with zinc oxide, indium oxide is readily reduced to metal by hydrogen. Furthermore, crude indium can easily be refined electrolytically.

There are two isotopes of atomic mass 115 and 113, the former being eleven times as prevalent as the latter. The atomic weight is 114·76. The metal crystals are face-centered tetragonal. The density is 7·3; the expansion coefficient, $3{\cdot}3 \times 10^{-6}$ at 20° C., as against $8{\cdot}8 \times 10^{-6}$ for platinum. Indium is much softer than lead. It can be extruded like lead, into very fine filaments. It will diffuse into lead and silver at relatively low temperatures.

The melting point of indium is 156·4° C., as against 231·86° C. for

From *Bulletin of Electrochemical Society*, Nov. 1945, p. 2.

tin; the boiling point is probably 2,650° C., as against 2,270° C. for tin and 767° C. for cadmium. Indium resembles tin in its physical appearance and, like tin, emits the characteristic "cry" upon bending a bar of the metal.

Indium is diagmagnetic. Its electric resistivity is $9 \cdot 1 \times 10^{-6}$, as against $11 \cdot 3 \times 10^{-6}$ for tin and $1 \cdot 78 \times 10^{-6}$ for copper. At temperatures near the absolute zero the resistance is zero.

The single potential of indium in a sulphate solution with normal metal ion concentration is —0·336 volt, as against —0·762 volt for zinc.

Chemically indium is relatively inert in dry air and is not soluble in dilute acids. There are three known oxides. In_2O (black), InO (white), and In_2O_3 (yellow). It forms sulphides, selenides and tellurides.

With chlorine, bromine, and iodine, indium forms mono, di, and tri halides. The corresponding di and tri fluorides are known but not the mono fluoride.

With the increased output and lower price of indium, both here and abroad, numerous applications of the metal have been suggested. Most important of these is the use of corrosion-resistant lead-tin bearings, many thousands of which went into service during the recent war. Other applications investigated include decorative, corrosion-resistant electroplating, electric contacts, thermometer liquids (Wood's metal + 18% In melts at 47° C.), indium-copper alloys for cooking pots, yellow-tinged glass, etc.

Oxide Metal Layers on Commercial Iron-Silicon Alloys Exposed To High Temperatures

By R. Ward

KNOWLEDGE of the nature and rates of oxidation of iron-silicon alloys is of great commercial importance, but little information of this nature is available. Investigations were therefore carried out to determine the effect of composition, temperature, time and atmosphere on the type of scale-metal layer obtained and to give some qualitative indication of the effect of these variables on the rates of oxidation. As this investigation was a study of silicon steels that are available commercially, extremely low-silicon and high-silicon alloys were not included.

From *Metals Technology*, 1945, Vol. 12, No. 5 and A.I.M.M.E. Technical Publication No. 1832, pp. 1–15.

The alloys used in the experiments were taken from heats of silicon steel that ranged in analysis from 0·7 to 5·8% silicon, and this composition range takes in most of the commercial silicon steels. The silicon contents of the various alloys are given in Table I. Other than iron and silicon, the alloys normally contained approximately 0·03% carbon, 0·07% manganese, 0·008% phosphorus, 0·02% sulphur, 0·07% copper, 0·01% tin and from nil to a trace of chromium and nickel.

All the alloys, except No. 8, which was an arc-furnace heat, were melted in open-hearth furnaces and were hot-rolled to 0·1 in. plate. Samples, ½ in. square, cut from each alloy, were polished on 000 emery paper immediately before oxidation.

Two different techniques were used in carrying out the oxidising treatments. One consisted simply of heating the samples with free access to air. In this treatment, the samples were set on edge on a refractory in an electrically operated controlled muffle-furnace. The second method used was one that maintained a definite atmosphere during heat-treatment. Samples were packed in iron tubes with ferric oxide (Fe_2O_3) and with a mixture of ferric oxide and iron powder to form effectively the magnetic oxide (Fe_3O_4). In a few special cases a small amount of water was added to the tube to determine the effect of water vapour on the oxidation process. Samples were heated in air at 800°, 900° and 1,000° C. and in closed containers, containing oxidising agents at 600°, 700°, 800°, 900°, 1,000°, 1,100° and 1,200° C. The time factor varied from 5 minutes to 240 hours for air oxidation and from time to reach temperature to 10 hours for the samples heated in the tube container. The various heat-treatments are given in Table I. After heat-treatment, each sample was sectioned across the centre and perpendicular to the broad face, mounted and polished by the usual methods with special effort to maintain the outer oxide layer. No etchants were used, as the scale layers were revealed after the polishing operation.

For any oxidation condition that allows subscale formation there is usually a composition limit above

TABLE I.—CONDITIONS OF OXIDATION (TIME OF OXIDATION IN MINUTES).

Oxidation Media		Air			Fe_2O_3						$Fe_2O_3 + H_2O$					$Fe_2O_3 + Fe$				$Fe_2O_3 + Fe + H_2O$		
Temperature ° C.		800	900	1000	600	700	800	900	1000	1100	1200	800	900	1000	1100	1200	800	900	1000	1100	800	900	1000
Steel	Si %																						
1	0·70	None	None	120	120	120	120	120	120	120	120	None	None	None	None	None	None	None	None	None	None	None	None
2	1·28	None	None	None	120	120	120	120	120	120	120	None	None	None	None	None	None	None	None	None	None	None	None
3	1·30	30	120	5 120	None	None	120 2700	120	120	120	120	120 1200	120	120	120	120	20	120	5 120	120	2700	1200	120
4	1·56	None	None	None	120	120	120	120	120	120	120	None	None	None	None	None	None	None	None	None	None	None	None
5	2·55	10	120	20 120	120	120	120	120	120	120	None	120 1200	120	120	120	120	20	120	40 120	120	2700	1200	120
6	2·78	30	120	None	None	None	120 2700	120	120	120	None	120	120	120	120	120	20	120	5 120	120	2700	1200	120
7	3·11	30	120	5 120	120	120	120 2700	120	120	120	None	120	120	120	120	120	20	120	5 120	120	2700	1200	120
8	3·17	10	120	20	None	None	120 2700	120	120	120	None	120	120	120	120	120	20	120	40 120	120	2700	1200	120
9	1·24	10 7200	120	20	None	None	120 2700	120	120	120	None	120	120	120	120	120	20	40	40 120	120	2700	1200	120
10	4·28	30	120	120	120	120	120 2700	120	120	120	None	120	120	120	120	120	20	120	5 120	120	2700	1200	120
11	4·69	10 7200	120	20	None	120	120 2700	120	120	120	None	120	120	120	120	120	20	120	40 120	120	2700	1200	120
12	5·81	None	None	120	120	120	120	120	120	120	None	None	None	None	None	None	None	None	None	None	None	None	None

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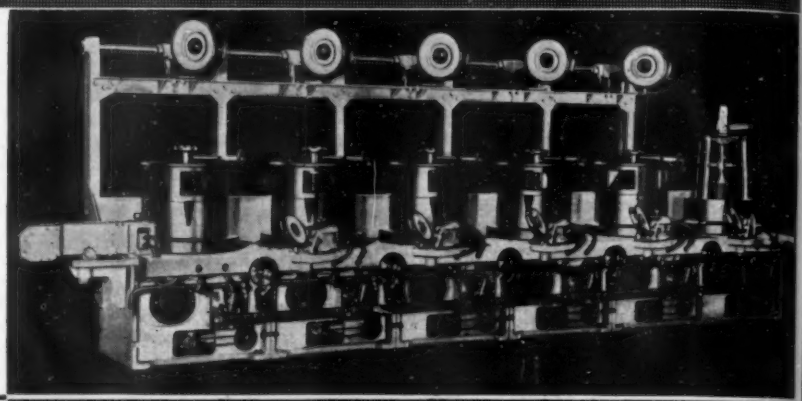

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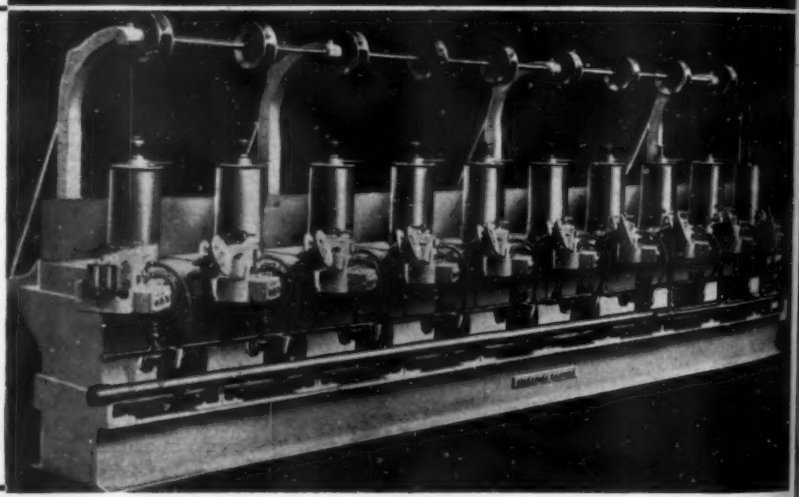

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which subscale is no longer observed. This limit depends on the oxidising conditions imposed, and variations of temperature, oxidising media and to some extent time, all have an effect upon the oxidising characteristics. A study of the micrographs illustrating the effect of these variables, and considered under the effect of composition and temperature and the effect of time and oxidising media, led to the following conclusions.

At temperatures below 800° C. and compositions below 1·56% silicon diffusion of oxygen takes place preferentially along the grain boundaries, while at temperatures below 800° C. and concentrations above 2·55% silicon diffusion of oxygen appears to proceed by lattice diffusion. For alloys low in silicon that are oxidised above 800° C., a layer of oxide particles is precipitated and this layer increases in depths with an increase in temperature and time. For alloys above 2·55% silicon the character of oxidation changes from "pearlite" type to a structure similar to "Liesegang" bands at 800° C. and to a globular type of structure above 1,000° C.

The globules of iron silicates formed at high temperatures in a number of cases are obtained first by precipitation of the silica particles and then by gradual solution of either iron or iron oxides that have been formed adjacent to the particle. A number of silica particles can possibly be precipitated in a concentration gradient when the silicon content has been reduced sufficiently to allow precipitation of the particle. Spalling of the metal-oxide layers is frequent where the Liesegang structure is obtained, whereas scales of the pearlitic type are most adherent. The character of the metal-oxide layers on the surface is dependent on the composition, temperature, rate of oxygen delivery to the surface and to a limited extent on the time. None of these factors can be over-looked in predictions of the type of scale to be formed.

From these conclusions it is evident that there is a definite break in the nature of the oxidation process of silicon alloys between 1·5 and 2·5% silicon. Layers of fine precipitate uniformly distributed, in which the size of the particles increases towards the outer surface of the metal, are found in all alloys, especially at high temperatures. The experiments also show that the composition limit for the formation of subscales is not clearly defined. If oxide particles of any composition, size, shape or distribution, that are grouped in band formation, are taken as subscales, then subscales can be said to exist even in 5·8% silicon steels when treated at 1,200° C., but if subscales are limited to the conditions that there is a band of uniformly dispersed oxide particles precipitated in a metallic matrix and that a layer of metal relatively free from oxides and adjacent to the outer scale is retained, then there is a composition limit for the formation of subscale somewhere between 1·5 and 2·5% silicon.

Induction Hardening of Plain Carbon Steels

By D. L. Martin and F. E. Wiley

THE results of an investigation of the effect of temperature, composition and prior structure upon the induction hardening characteristics of plain carbon steel are presented. Five plain carbon steels covering the range 0·2 to 1·1% carbon, Table I, were studied in the investigation. All the steels were austenitised for one hour in a nitrogen atmosphere to prevent decarburisation and cooled in the furnace or air to produce the desired structure. Steel D was also quenched in brine from 800° C. and tempered at 500° C., and steel C was tempered at 500° C. after normalising. Steel D, after normalising, was also spheroidised by heating for 50 hours at 650° C. and steel E was spheroidised in the as-received condition. All the steels in their furnace-cooled condition, as hardened, tempered or spheroidised, were induction hardened. The induction hardened specimens were cut transversely through the centre (under a water spray) and Knoop hardness readings at 0·01 in. intervals were made across the hardened case into the core. A micro-examination of all specimens was made after the hardness measurements were completed.

The results obtained on over 50 samples indicate that the basic metallurgical principles of induction hardening are no different than those of the conventional hardening methods. The properties and structures are different (1) due to a surface layer of martensite, and (2) the lack of homogenisation in the prior austenite. The pearlite starts to transform between 700 and 750° C., and as the heating temperature is increased, the austenite areas grow by solution of the undissolved carbide or free ferrite. A minimum temperature is reached at which full hardness is obtained when quenched, and this temperature is largely dependent upon the distribution of cementite in the ferrite matrix, varying with carbon content and prior structure. For furnace-cooled structures the minimum temperature for full hardening ranged from 750° C. for the 1·1% carbon steel to over 1,200°C. for the 0·17% carbon steel. Only about 90% martensite is required to obtain essentially full hardness in an induction heated specimen.

TABLE I. COMPOSITION OF STEELS.

Steel	Composition			Austenitising Tem. °C.
	C	Mn	Si	
A	0·17	0·87	Nil	900
B	0·30	0·66	0·18	900
C	0·47	0·19	0·13	850
D	0·80	0·34	0·27	800
E	1·10	0·44	0·19	900

The heating temperature is the most important variable in induction hardening. Induction heating to high temperatures above the minimum temperature result in complete transformation to austenite and elimination of carbon concentration gradients. For extreme temperatures, the hardness of all steels decreases due to homogenisation and deeper penetration of the hardened layer, and at intermediate temperatures the hardness may be at a maximum due to optimum internal stress and micro-structural conditions. The high compressive stresses in the hardened layer, less retained austenite, and carbon segregation effects all contribute towards a slightly higher hardness in an induction hardened steel compared to a completely furnace-hardened specimen of the same steel. In general, as the induction hardening temperature is increased, these effects are eliminated due to the greater depth of hardening and homogenisation, and the hardness decreases. The drop in hardness is not serious so that a wide temperature range exists above the minimum hardening temperature where satisfactory properties are obtained. For applications, where fatigue properties

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are important, it may be necessary to limit the upper heating temperature in order to obtain optimum internal compressive stresses in the hardened case.

Prior structure is of major importance in hypoeutectoid steels in which a shallow depth is desired. A sorbitic structure has been found to transform to austenite at lower temperatures and at faster rates. For applications where furnace equipment is not available for correct prior heat-treatment, it is possible to obtain equally satisfactory results by a double induction hardening treatment. The purpose of the first treatment is to obtain a satisfactory carbon distribution by heating to a high temperature and quenching, while the second treatment is to produce the desired hardening layer at the surface.

Increasing the carbon content of an induction hardened steel is desired since it facilitates formation of austenite increases the maximum hardness and decreases the influence of prior structure. Normalised steels above 0·45% carbon respond satisfactorily to induction hardening methods. Tempering of induction hardened specimens at low temperatures relieves at least in part the high compressive stresses in the hardened case. Due to the beneficial improvements resulting from internal compressive stresses, tempering is not advised where wear resistance and fatigue are of major importance. Cracking or spalling of induction hardened parts is not likely to occur due to the uniform hardened layer and the high compressive stresses.

A High Temperature Electric Tube Furnace

By J. W. Gartland

FOR a number of years carbon tube furnaces have been in use. Recently, however, a new type has been developed, the design of which has evolved over a period of several years, and has proved a practical and convenient high temperature source. Its advantages are :—

1. Rapid attainment of any desired temperature up to 3,000° C. (30 mins. or less).
2. Ability to hold any final temperature within ± 20° C.
3. An optically clean black body chamber to assure precise temperature measurements suitable also for optical pyrometer calibration.
4. A dependable water-cooled terminal whose service is measured in years and which is so positioned as to allow access to the hot chamber at all times.
5. Uniform black body conditions over at least 50% of the resistor length.
6. An efficient and refractory insulation which effectively minimises heat losses.
7. Reasonable heater-element life combined with accessibility for easy replacement.

The tube furnace consists of a refractory hearth which serves as a supporting bed for the vertically positioned, water-cooled end terminals and the communicating bus bar system. The graphite blocks which comprise the lower and tube-contacting portion of the terminals cradle the 2·625 in. by 2 in. horizontal resistor tube member which extends approximately 6 in. outside the contact area and is maintained cool enough by the terminals to be exposed to air at this distance. The carbon black thermal insulation around the tube is confined by loosely laid up sides of fire brick and removable three-sided ends, constructed from transite, which slip over the carbon tube and around the side walls. The temperature observations are made with an optical pyrometer through a side-arm carbon tube inserted through the mid-point of the heater tube wall into a black body chamber.

The atmosphere of the black body chamber is kept optically clean by sweeping with tank nitrogen. Internal radiation along the length of the tube is prevented by using several graphite capsules, on either side of the black body chamber, which have only a small clearance with respect to the tube wall. The ends of the tube are closed by loose-fitting graphite plugs to permit escape of the sweep gas and distillation products.

The life of the tube depends upon the upper temperature limit at which it is used. Above 2,500 °C. actual volatilisation effects undoubtedly become an important factor which decreases life. Little is known of the vapour pressure of carbon except that somewhere in the temperature range between 2,350° and 2,600° C. its vapour pressure is approximately one millimeter of mercury and that, at the temperature of the carbon arc, 3,950° C. its vapour pressure is quite high but not necessarily one atmosphere. The exterior of the tube photographed in Fig. 3 showed definite evidence of localised surface erosion, which may have been the result of evaporation. This tube was replaced after about 5 hours at 3,000° C., although it had not failed. A useful life between five and ten hours may be expected at this temperature. Below 2,500° C. a tenfold increase in life is reasonable and, with a gas purification train, a useful life of two hundred hours has been realised.

The construction of the furnace was developed to permit quick replacement of the tube element. With experience in use and operation of this furnace, replacement of the resistor tube can be completed in one-half to three-quarters of an hour after the insulation has cooled below its ignition temperature.

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Sectional Carbide Moulds

AFTER six years of experimentation, the Firth-Sterling Steel Company has announced that sectional carbide nib moulds show definite advantages in the field of powdered metallurgy over the solid mould. An increase is claimed to have been made by their use of from seven to ten times the production obtained with solid steel moulds. The experiments were carried out in a group of industrial plants and so represent actual operating conditions.

A plant, in which tungsten-silver electrical contacts were formed, used pressures of from 60 to 70 tons and obtained from 27,000 to 124,000 units with a wear of less than 0·001 in. on the mould. As the tolerance on the contacts was 0·005 in., it was estimated that 500,000 of these contacts could be formed before the nib needed regrinding. It was further estimated that five recuts could be made, giving a production life of 2,500,000 units for the mould. This assumption has been justified by results from other plants.

The use of sectional nibs provides "controlled cracks" at sharp corners and relieves the stresses at these points that otherwise would cause failure by fatigue, resulting in cracking and chipping.

A big advantage claimed for the sectional nibs is the possibility of recutting them a number of times to the original size for long production runs. Also, a sectional nib may be recut to a larger size which will, it is estimated, reduce mould costs by about one third.

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